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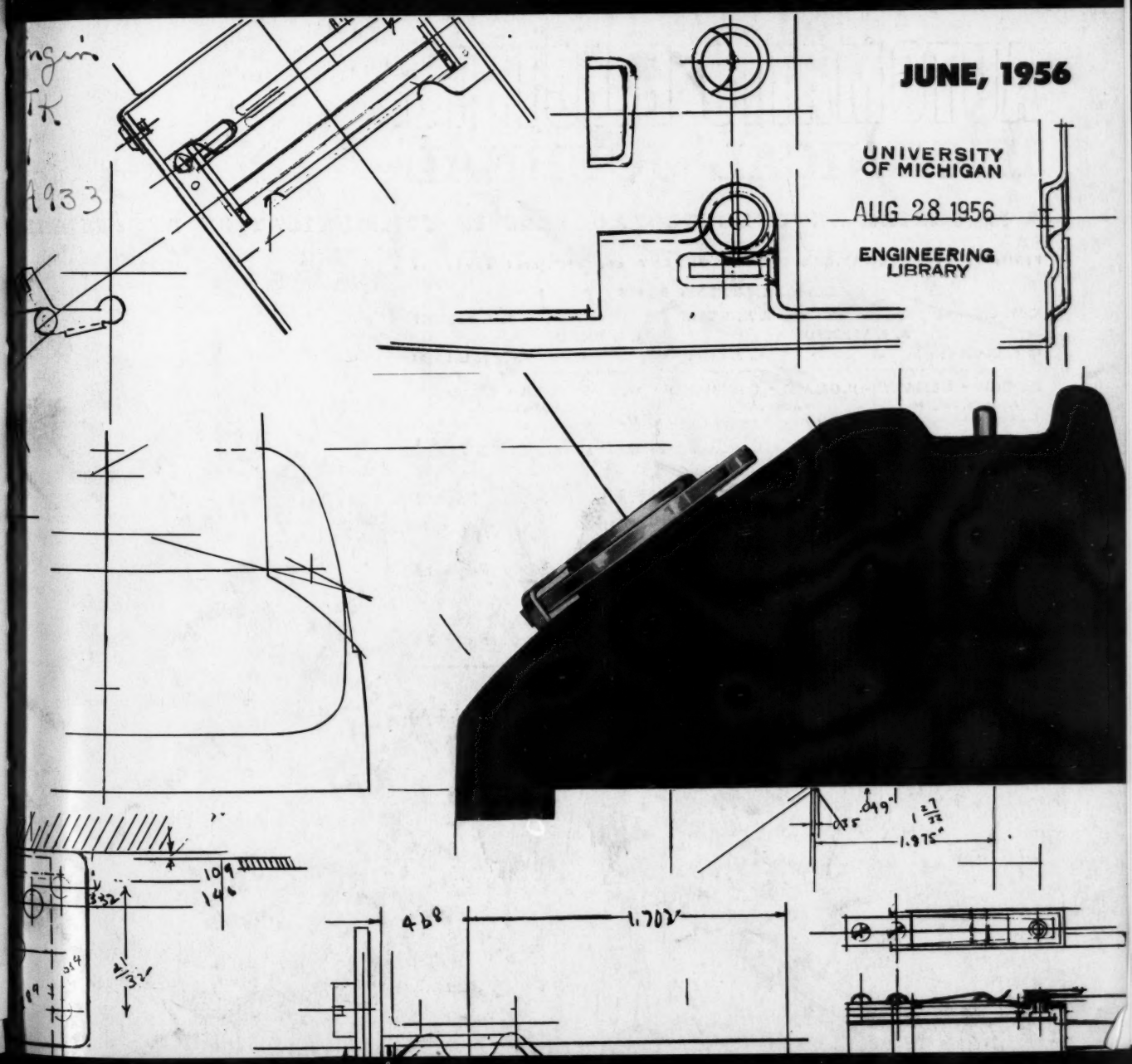

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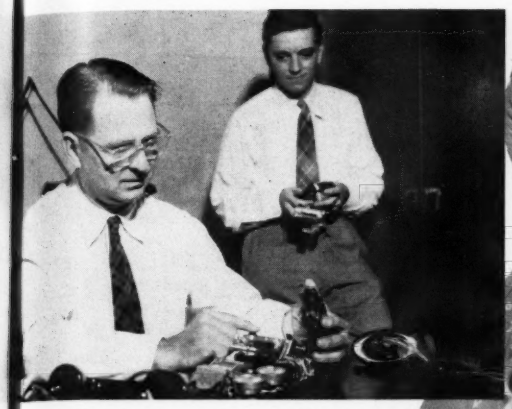
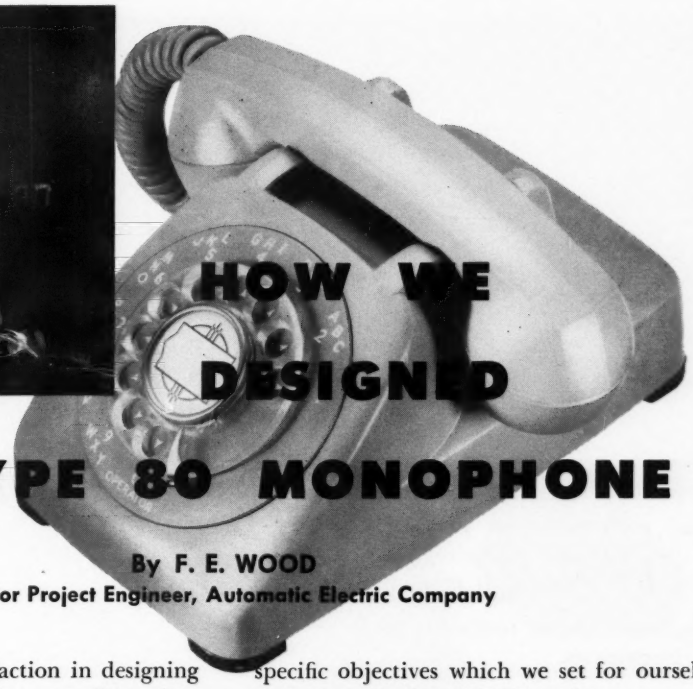
WALTER AXELSEN, *Editor*, 1033 W. Van Buren Street, Chicago 7, U.S.A.





HOW WE DESIGNED THE TYPE 80 MONOPHONE

By F. E. WOOD
Senior Project Engineer, Automatic Electric Company

There is tremendous satisfaction in designing a telephone – more satisfaction, possibly, than in anything else we do in the telephone field. That's because the telephone is such a *personal* thing.

All telephone equipment must work – and work efficiently, dependably, and with a minimum of maintenance. But the telephone instrument must do these things even though subjected to misuse and abuse from telephone users; in this respect it differs from all other telephone equipment, which is handled only by the telephone company's experts, trained to give it the care it deserves.

There is one other big difference. Because the telephone instrument is used so intimately by the subscriber – because it stands constantly in his home or office as a symbol of the telephone company – it must be pleasing to the senses. Sight, hearing, feel, and even smell, affect the subscriber's opinion of his telephone (only the sense of taste is, so far, not involved)! In other words, the telephone designer must come up with an instrument that is not only technically sound but also esthetically pleasing.

These were Our Objectives:

To see what that means, consider the many specific objectives which we set for ourselves in designing the Type 80 Monophone:

1. Since the purpose of the telephone is to transmit intelligence, transmission must be of the finest commercial quality. (This is a vast subject in itself, and I shall not try to discuss it here. Harold C. Pye and his assistants were responsible for this phase of development, and he will discuss it in a future issue of the Journal).

2. *Appearance* must be outstanding. Contours must be pleasing from every angle – and of course, to suit modern tastes, *color* must be made available.

3. The design of the telephone must be such that it would stand repeated drops to the floor without damage. (To those of us who have never in our lives dropped a telephone, telephone companies' experience with telephone breakage is truly amazing!)

4. Operation must be as reliable as it is possible to make it, so as to hold servicing to a minimum. In this connection, everything possible should be done to reduce "receiver-off-hook" trouble, which is one of the most annoying complaints for the operating company.

5. Servicing, when necessary, should be quickly and easily accomplished. This meant

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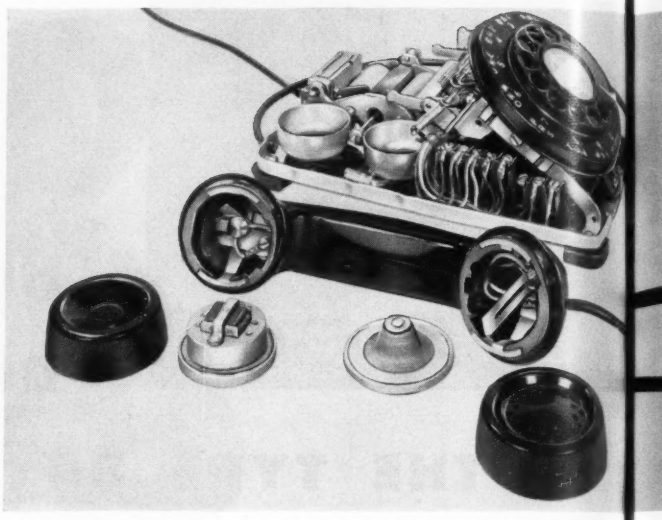


mounting all components on the steel baseplate, and "screwdriver" mounting and connecting them, to facilitate their removal.

6. Ringing should be of uniformly high volume at all frequencies.

7. Feet must be provided which will prevent the telephone from slipping during dialing or ringing; these feet must not stain any surface on which the Monophone might be placed.

8. The instrument must be easy to pick up and move about.

9. The new instrument should permit operating companies to provide economical, improved service to their customers, and should increase operating revenues by encouraging use of the telephone, and attracting new subscribers.

10. In short, the new Monophone must provide the "best in everything," yet it must be designed so it could be offered at a reasonable price.

We considered these to be the "must" requirements for our new instrument. Beside these there were many "desirables":

1. All transmission components (except receiver and transmitter, of course) should be housed in a single container which could be impregnated to withstand any environment in which a telephone would be used. The transmission unit should provide sufficient terminals so all circuit connections made by the operating companies would be made at the "terminal board" with no tool but a screwdriver.

2. The ringing condenser should be a part of the ringer assembly. Thus, when an operating company changed a ringer (for example, when a number change required that the Monophone be changed from 16 2/3 cycles to 33 1/3 cycles) the correct condenser would always be available and used.

3. A volume control should be placed on the ringer so a subscriber could regulate the ringer volume to suit his or her individual desire. (There is some disagreement as to whether this is desirable, so we manufacture Type 80 Monophones with straight-line ringers both with and without volume control; no volume control is available for harmonic ringers).

4. Dial and hookswitch spring assemblies should be provided with dust covers.

Figure 1. Type 80 Monophone, in standard black.

5. All contact springs should be of twin-contact type to provide more reliable contact closure. There should be provision for adequate hookswitch springs for special circuits.

6. Hooklatch facilities should be provided. The hooklatch is a mechanical device which stops the hookswitch in a partly operated position (when the handset is removed) so only the receiver is connected to the circuit for listening purposes. A button is pushed to allow the hookswitch to operate fully and connect the dial and transmitter.

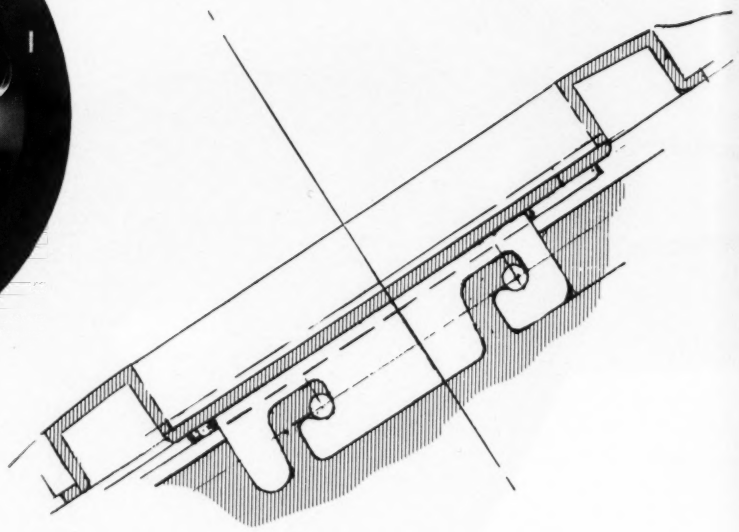
7. Provision should be made so the hookswitch could be placed in the "handset on cradle" position (making the Monophone ready to receive calls), even though the housing and handset were off the Monophone; this would permit a service man to inspect the telephone without busying the line or losing important telephone calls. The hookswitch must automatically restore to operating condition when the housing is assembled on the Monophone.

For a short time we considered making a "convertible" telephone – that is, a desk set which could be converted into a wall set. We felt, however, that the demand for wall telephones justifies the designing of another instrument specifically for this use, and therefore it was not desirable to make any compromises in the design of a desk telephone, in order to meet this need. The "convertible" idea was therefore abandoned.

The desk telephone which we developed, incorporating these ideas and many others, is the Type 80 Monophone, shown in Figure 1.

The Dial, and Number Plate

One of the first considerations in designing the telephone was the angle of the dial and



the design of the number plate. Investigation showed that, with a person of average height seated in a chair of normal height, and at a desk of normal height, a dial angle of about 35 degrees would give the best visibility of the numerals and letters, and also would place the dial at the most convenient angle for dialing (convenience of dialing is important because, if the angle is incorrect, the subscriber's finger is likely to slip out of the finger wheel).

The size, shape, and location of the letters and numerals was important. We felt that, on most of the telephones we had seen, either the numerals and letters were too small, or they were not located so as to be clearly visible and readily identified with the proper hole in the finger wheel of the dial. Obviously if the subscriber cannot readily see the correct numerals and letters, and readily identify them with the correct finger hole, he or she is likely to guess, and wrong numbers will result.

Inasmuch as Auotmatic Electric Company already had a dial which was unsurpassed for performance and reliability, the obvious thing to do was to use this dial in as near its existing form as possible. This would make it possible to use any Automatic Electric dials the customer might have, with very little or no modification. Accordingly, it was decided that new number plates should be designed into which the Automatic Electric Company Type 51 (or the earlier Type 24) dial would fit.

A few of the many types and shapes of number plates designed are shown in Figure 2. As may be seen from this photograph, the letters and numerals were arranged in different configurations or patterns. In addition, various sizes of letters and numerals, types of characters, widths of stroke or line, and spacings were tried. While it is not very apparent from the photograph, these number plates were also of several different contours. Some of them were convex or dished downward. Some were flat. Some were domed upward. Some of the number-plates underneath the finger wheel were domed, and made from clear plastic with the

numerals on the back, so as to cause the numerals to be enlarged or magnified. Others had the numerals engraved and painted in a manner which gave a three-dimensional effect. Various color combinations were used, including metallic paints. In short, almost anything which would increase the legibility of the numerals and letters was tried.

As a result of all these trials, we decided to make the number-plate convex, in order to make its contour blend in with the contours of the proposed housing. We also decided to use number plates molded by the double-injection molding process, since this process places the numerals and letters on the surface of the plate and provides an almost indestructible number plate.

We had intended to make the number-plate with the same bright polished surface as the housing. However, when viewing the plate from many angles and under various lighting conditions, we found undesirable highlights or reflections occurred, which tended to hide the numerals and letters and under some lighting conditions made it very difficult to see the letters or numbers clearly. A matte finish on the surface of the plate removed these undesirable reflections.

Viewing the number plate from various angles also disclosed that from the angle a child might view the dial, the flat finger wheed had a tendency to hide the "3" and "4" on a metropolitan number plate. A domed finger wheel corrected this difficulty and also blended the contour of the dial more gracefully into the contours of the proposed telephone.

To better identify the groups of letters and numerals with the finger holes, an arrow was placed under each hole in the finger-wheel to guide the eye to the correct group.

The number plate finally selected is the one at the lower right in Figure 2.

For use with existing dials, the number-plate was made in the form of an adapter ring which could be simply slipped over the dial before it was screwed to its mounting plate. A new dial was also designed with a one-piece number-plate (combining the old "number-plate" and the new extended plate); this plate has a flange projecting upward in the center, providing better dust protection. As this plate is molded of thermoplastic, it is available in colors to match all colors of Monophones.

Design of the Housing

An industrial designer who had previously demonstrated his ability in designing equipment for Automatic Electric was now commissioned to suggest the styling of the telephone.

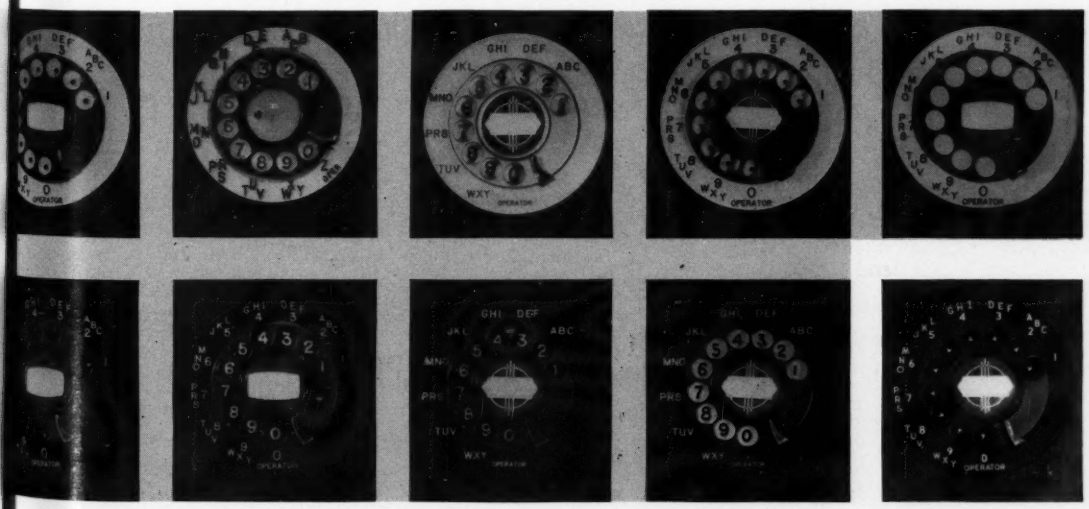


Figure 2. Some of the number-plates developed for trial on the Type 80 Monophone. Plate adopted is shown at lower right.

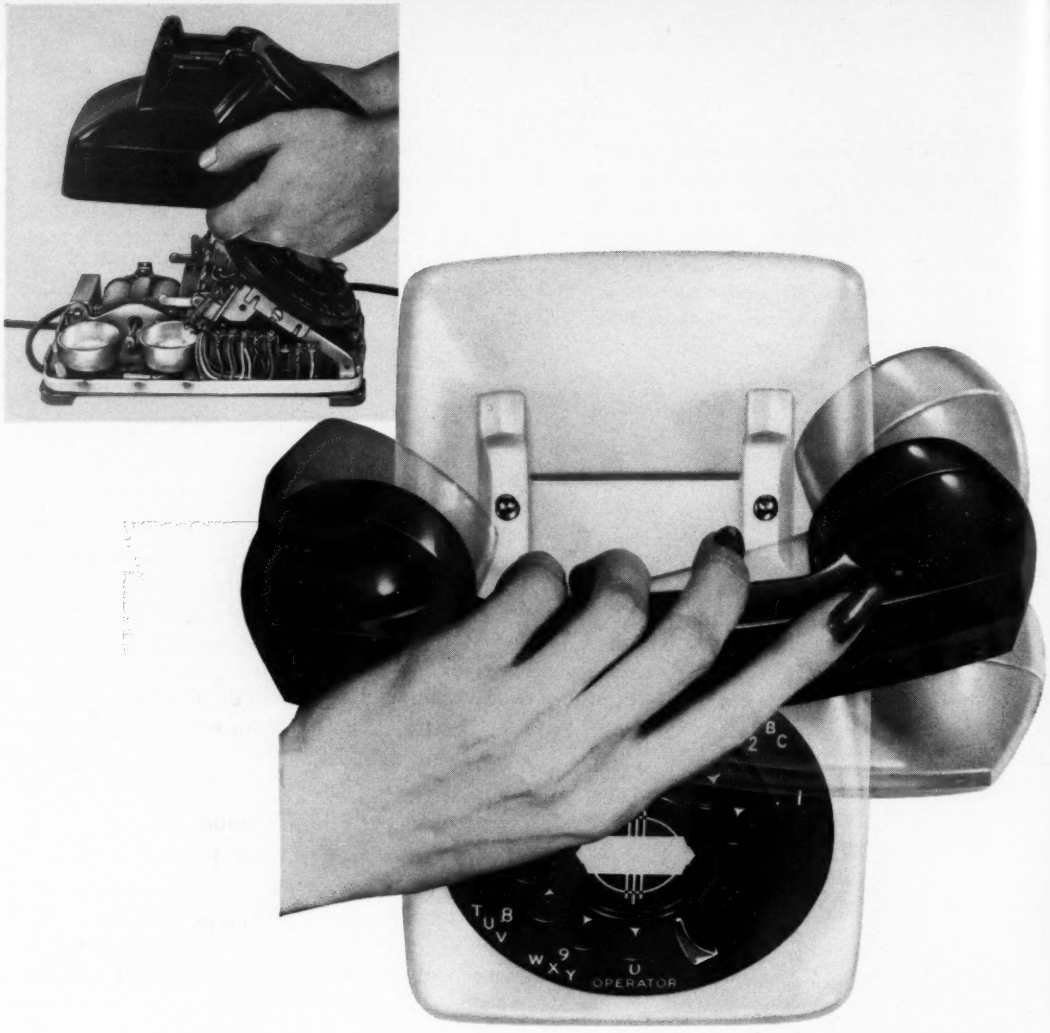


Figure 3. The handset of the Type 80 Monophone "walks" into place, even though it is placed in front of the cradle.

His design consisted essentially of a gracefully curved, approximately rectangular, box section (to house the majority of the apparatus) as a base, intersected at the proper dial angle by a gracefully curved, approximately square, box section whose function was to house the dial. The cradle section was blended into both of these sections and in back of the dial housing section; the contours of all three sections were then reworked to blend into a smoothly integrated unit which was unquestionably the best-looking model of a telephone we had seen.

Taking this as the basic design of our housing, we went to work to incorporate into it all the features we had decided upon for our new instrument. We wanted its lines and curves not only to enhance the beauty of the Monophone, but also to improve its performance.

How could the curves and contours of a telephone housing possibly improve the performance of a telephone for an operating company? That's a good question, and the answers are many. But the first, and possibly the most important, example is the "Walking Handset" which we developed to reduce "receiver-off-hook" trouble.

"Receiver-off-hook" means, of course, that the subscriber may have carelessly replaced the handset on the telephone in a way which has not properly operated the hookswitch. This means that his line, the line to which he was last connected, and the central-office equipment

which connected them, are all held operated; all the other parties on the two lines (which may total 19) are denied service for an indefinite period! This sort of thing can be a real nuisance for the telephone company; yet no other telephone had really attempted to solve this problem.

Examination of these other instruments will show that almost all of them have cradle posts projecting above the body of the telephone. It may be demonstrated that it is very easy to place the handset in front of the cradle posts in such a way that it will stay on the telephone and appear to be in place, yet cannot operate the hookswitch. It was our object to make this impossible – to assure that a handset replaced in this manner would either "walk" into the cradle, or else fall off the Monophone (see Figure 3).

Actually the principle of the "Walking Handset" is very simple. Gravity tends to pull an object downward. Thus, a block will slide down an incline (and even over a smaller object placed in its way) if the friction developed is less than the pull of gravity.

In the same way, the handle of the Type 80 Monophone handset slides up and over the front of the cradle as the handset rotates into place. While the handset appears to lift itself, actually the center of gravity of the handset must be falling at all times in order to provide the motive force to rotate the handle into place.

The first step in this development was to lower the cradle and raise the part of the housing above and behind the dial as much as possible without detracting from the appearance of the Monophone. It was necessary to determine the amount of stroke necessary to operate the hookswitch, and so contour what remained of the front posts of the cradle that the handset would come directly down on the hookswitch plungers and provide the necessary stroke. In order to reduce the amount of friction, a bevel was added to each of the posts so the handle would slide on a single line on each post. This line was raised as high as feasible on the surface in front of the posts to prevent the handle from "hooking" on them, and was blended into the front contour so as not to detract from the appearance of the telephone.

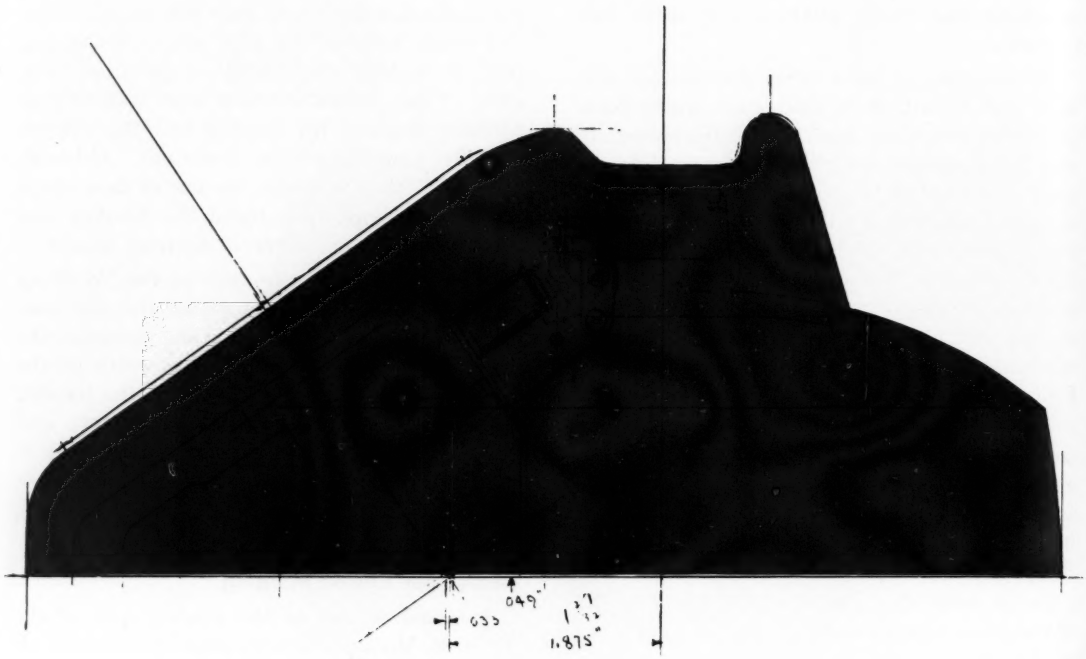
To further regulate the position of the handset in order to prevent sticking, the curves on the front surface outside the cradle, as well as the slope downward from these curves, were carefully contoured. The radii on the handset where the handle joins the cups at either end, the contour of the transmitter and receiver caps, and other contours all play a very important part in making the "Walking Handset" possible. Thus, contours which seem only to give pleasing shape to the housing and the handset actually have important functions. Although functional, these contours, because of their shape and simplicity of line, blend the handset and housing into a telephone of unusual beauty.

In addition to the contours for the "Walking Handset," we carefully regulated the side contours of the cradle, the spacing between the front and back cradle posts, the width of the cradle in relation to the length of the handle, the transmitter and receiver cap contours, and the adjustment of the hookswitch so that it will be operated in any position the handset can be placed on the cradle without falling off the telephone (see Figure 4).

Design for Plastic Molding

A glance at any of the phonographs of the Type 80 Monophone will show that almost all lines and surfaces are gracefully curved – only a few lines and surfaces at the hookswitch are straight or flat. In addition to their esthetic value, these curved lines and surfaces have a

Figure 4. Even if left in this position, the handset of the Type 80 Monophone will always actuate the hookswitch.

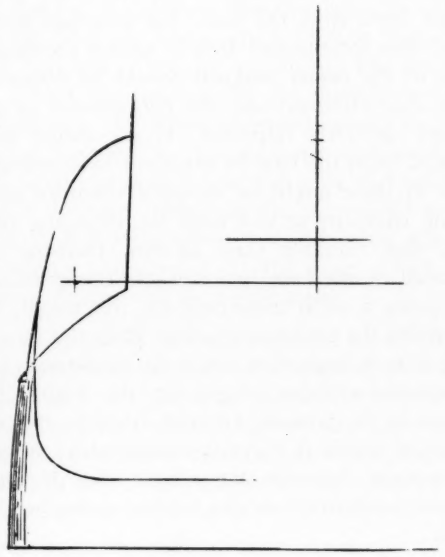


very practical purpose in the process of molding the plastic parts.

The housings of Type 80 Monophones are molded of thermoplastic. Parts molded of this material may vary somewhat in shape, because the pieces do not always cool evenly, and slight warping occurs. These conditions would cause straight lines to be wavy, and flat surfaces not to be flat. Thus, these slight imperfections (which in no way impair the usefulness of the housing) would detract from its appearance, whereas they are virtually impossible to see on gracefully curved surfaces.

The decision to use thermoplastic molding material instead of the less costly thermosetting phenolic plastics was based largely on its greater strength. As previously mentioned, a phenolic housing did not have the strength to withstand being accidentally dropped from a desk to the floor; certain types of thermoplastic materials, however, do possess sufficient strength (if used in a properly designed housing) to withstand repeated drops.

The amount of heat normally used in molding thermoplastic compounds does not cause a chemical reaction or polymerization. Therefore when an article molded of thermoplastic molding compounds is again subjected to heat, it will either soften or melt, depending upon the temperature to which it is heated. It is therefore necessary to choose a thermoplastic molding compound whose softening temperature is above the highest temperature to which the Monophone will be exposed, and whose impact strength is such that the Monophone will not break when it is accidentally knocked to the



floor. Usually the thermoplastic molding compounds with the lowest melting point provide the greatest impact strength. Therefore, a material with reasonable balance between properties must be selected; it must provide strength to withstand dropping, yet must not soften at any temperature to which it will be subjected in service.

The growing demand for color was another, and equally important, reason for using thermoplastics. These materials are available in an almost unlimited range of colors as well as black, whereas only a very limited color selection is available in phenolics.

Designing for thermoplastics requires a very different technique from designing for phenolics. Sections must be as uniform as possible. Contours must blend smoothly into one another and must not be too thin. Because the molded piece is soft and somewhat flexible when it is removed from the mold, adequate stiffening ribs must be provided. (These ribs also greatly stiffen and strengthen the molded piece when in service.) The thickness of the ribs in proportion to the outside housing must be carefully controlled to prevent the ribs from showing on the outside. Proper taper on the parts must be provided so the piece may be ejected from the mold without distorting the molded part. Special care must be used in designing sections and contours around inserts.

In order to eliminate the sound openings in the sides of the housing, the steel base of the Type 80 Monophone is raised off the desk by means of feet, and the sound openings are in this base. A space between the sides of the steel base and the housing also permits sound to escape.

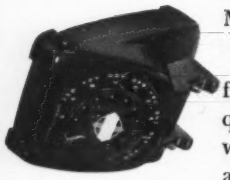
To support the housing as much as possible, and reduce breakage, three threaded inserts are set into the housing. These inserts permit screwing the steel base solidly to the housing in three places. We believe that the additional strength afforded the Monophone by holding it tightly together as an assembly, and thus reducing breakage, far outweighs the extra effort of putting in an additional screw or two. It is obvious that no "clip together" or "single screw in slot" arrangement could give the support to the housing that is afforded by screwing the housing solidly to the drawn steel base.

Further support was given the housing by extending many of its ribs so they will bear on the flange of the steel base. At points of heavy strain, extra ribs were placed in the housing, thus doubling the bearing strength. Small projections on the ribs hook in behind the flange on the steel base and help keep the housing in the proper shape.

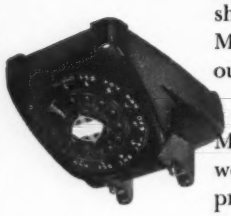
Drop Tests

Since there is no way to tell how the telephone might be dropped, it was decided that an assembled Monophone would be balanced on the edge of a desk and allowed to fall to the floor. To ensure that it would strike the floor in all likely positions, the Monophone would be pushed off the desk twice from each side.

Thus a total of eight drops would be made. To make certain that the floor would be as hard as it might be in any subscriber's premises, a ¾" steel plate covered with a piece of ¼" thick Masonite would be used as the "floor."

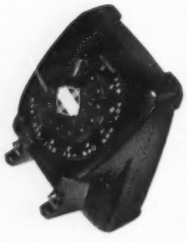


Inasmuch as the apparatus in a telephone is fairly heavy, the shock of hitting the floor is quite severe. The Monophone housing was to withstand this test without breaking. This was a very difficult goal but we felt that if we could achieve it, the saving to an operating company should be considerable. Tests on completed Monophones have shown that we have attained our goal, but only after considerable struggle.

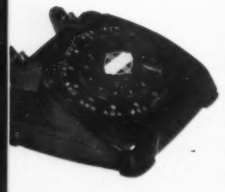


When the first housings for the Type 80 Monophone were obtained from the mold, they were very promptly drop-tested – and just as promptly broke! Pictures of the Monophone being pushed off the desk and hitting the Masonite-covered steel plate were therefore taken with the high-speed camera at about 3500 frames per second. Following study of these pictures slight revisions were made to the mold and an entirely different plastic used to mold new housings. Drop tests on these housings showed they had more than adequate strength. Many were unbroken after 58 drops!

Our high-speed photographs disclosed something else of considerable interest. To the eye it appears as though the Monophones merely hit and roll over. The camera reveals, however, that with the housings now being used, Monophones hit and bounce almost like a rubber ball, and spin and hit again. The resilience of the housing is an important factor in reducing breakage.



Since the components of a telephone are fairly heavy, it was necessary to provide not only a tough housing, but also adequate support for the components – adequate support, in this case, being a sturdy base. A sturdy base can be obtained in two ways: 1. By using very heavy metal; 2. By using lighter material and drawing a rim around the outside. The second method is, of course, preferable, since it reduces the weight of the telephone. Everyone is familiar with the fact that a "U" channel is much harder to bend than a flat sheet; also, that a drawn box is much more rigid than a channel section. We therefore designed the base as a drawn box.



The Type 80 Monophone base is more than just a drawn box, however – it is so shaped that it supports the housing in many places, particularly at the corners. The bottom of the base is also drawn down into many shapes to properly support the components – and in some cases, space them from the base. For example, if the steel base were placed directly against the ringer, one of the ringer magnets would be magnetically short-circuited and the performance of the ringer seriously impaired. If the ringer were spaced from the base by means of loose washers, one of these might be dropped when an operating company service man was changing ringers, and valuable time be lost. Drawing the bottom of the base into suitable configurations provides a solid mounting for the ringer, yet provides the necessary spacing. The solid mounting is very important since the performance of frequency-sensitive ringers at the higher frequencies is seriously affected (that is, the volume of sound is lowered considerably) by any movement between the ringer and the base. These configurations also further strengthen the base.

Other drawn shapes on the base securely clamp the line and handset cords, yet guide them so they do not interfere with the ringer, nor do they interfere with replacing the housing. Still others make it possible to locate the screws holding the housing so that it is only necessary to place the housing over the front two screws and let it fall into place. Result– no troublesome alignment or cross-threaded screws.

Four non-staining feet are provided on the base, which firmly grip the desk top and prevent the Monophone from moving easily. It is very important that the Monophone stay firmly in place during dialing; if a telephone slips during dialing, the result is very likely to be a wrong number.

The feet serve other, not so obvious, purposes. They raise the base off the desk, permitting the use of sound holes in the base, instead of sound openings in the shell. The feet are Neoprene, securely bonded to steel inserts, and placed at the corners of the base so that in many cases they greatly reduce the shock to the housing when a Monophone is dropped. No matter how

the Monophone lands on the floor, the placement of the feet is such that additional support is given the housing.

The steel inserts in the base serve as non-losable nuts or threads for the screws which hold components to the base. The inserts in the front two feet hold the screws which in turn hold the front two legs of the dial mounting. The inserts in the rear two feet provide the threads for the cord clamps. By using threaded inserts in the feet, we were able to provide many more threads than would have been the case if we had merely tapped the base; threads in the base would strip easily and, if stripped by a service man, would necessitate replacement of the base, which is both expensive and time-consuming.

In the Type 80 Monophone there are no components held to the base by threads in the steel base. There are sufficient threads in the steel inserts in the feet so it is very doubtful if stripping will ever occur. However, if a foot is damaged it is very easily replaced at the subscriber's premises by a service man.

The ringer is securely mounted to the steel base by three screws—a stable mounting being assured by the use of a three-point suspension.

The correct condenser for each ringer is mounted directly on it. This ensures that the correct condenser will be available any time a Monophone is converted to ring on another frequency. The ringer-condenser assembly is provided with leads with spade terminals, so it may be changed on the subscriber's premises without the use of a soldering iron.

Straight-line ringers (non frequency-sensitive) are available with a sound-adjusting wheel, which projects through the bottom of the steel base, enabling the subscriber to adjust the volume of sound to suit his or her individual preference. As normally furnished, the sound-control wheel will not permit the subscriber to turn the ringer completely off, as this might result in lost calls. This volume control is effective only when the straight-line ringers are operated on 16⅔ cycles, 20 cycles or 25 cycles; it is not effective when 30-cycle or higher frequencies are used.

Since many operating companies may not want a volume control, the Type 80 Monophone is also available without this feature.

In order to increase the volume of sound of the higher frequency ringers, they were redesigned to provide a magnetic path of high initial permeability (at low flux densities) between the two coils. The two ringer cores were likewise made of nickel-iron having a high initial permeability at low flux densities. Thus by providing a thin piece of nickel-iron between the nickel-iron cores and the heelpiece, and reducing the d-c resistance of the coils, we were able to keep the impedance of these higher-frequency ringers (at talking frequencies) to the same high value as the ringers for lower ringing frequencies. Since at ringing frequencies the current through the ringer coils is much higher, resulting in higher flux density, the thin piece of nickel iron becomes saturated and most of the magnetic flux travels through the heelpiece. Due to the flux path passing through an ordinary iron heelpiece, and due to the lowered d.c. resistance of the coils, we have a low-impedance ringer at ringing frequency. Thus at the low voltage of the talking frequencies we have a high-impedance ringer, and at the higher voltages of the ringing frequency we have a low-impedance ringer.

The electron tube required for superimposed ringing can be supplied when this method of ringing is used; space for this tube is provided in the housing.

The transmission network is located at the front of the steel base. This network contains the induction coil, talking condenser, and balancing network. By placing all these important components in a single housing, and filling the housing with a non-hardening, non-shrinking and moisture-resistant impregnant, we are able to protect the "heart" of the Monophone against almost any climatic condition in which a human being is likely to use a telephone. All circuit terminations are conveniently made to screw terminals on the top of the transmission network. This practically eliminates any need of using a soldering iron on the subscribers' premises when servicing a telephone.

Hookswitch Mounting

To ensure a stable mounting for the hookswitch and the dial, a sturdy three-leg frame was designed. This frame is fastened securely to the

Figure 5. This side view shows the coil spring that actuates the hookswitch springs, and the curved rib on the housing that returns the "Installer's Hook-Lock" to normal position.

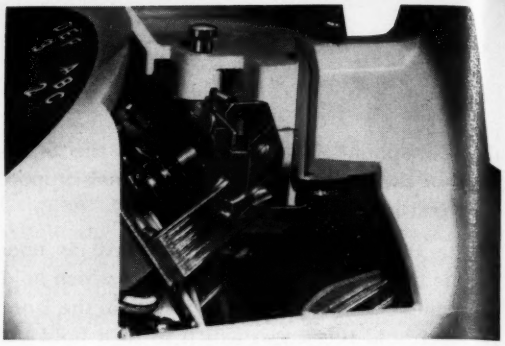


Figure 6. The optional hooklatch is released by a button in the cradle.

base at three points, and provides all the stability of a three-legged stool! To this mounting frame the hookswitch is fastened securely.

The handset of the Type 80 Monophone is appreciably lighter than former handsets. This lightness, of course, greatly reduces fatigue from holding the handset when using the Monophone. But it also necessitated the design of an entirely different type of hookswitch. Ordinary hookswitches build up pressure rapidly toward the end of the stroke, and require a heavy handset to completely operate the hookswitch. (In a former type of handset, in fact, it was necessary to mold a lead weight in one end, to ensure that it would operate the hookswitch).

Examination of a Type 80 Monophone hookswitch will show that it is of the "reverse-action" type—that is, a coil spring furnishes the power to operate the hookswitch springs (see Figure 5). The pressure required on the plungers to operate the hookswitch springs is lowered to a reasonable level at the beginning of the plunger stroke by the action of the coil spring and contact springs working against one another. As the plungers are depressed, the pressure of the contact springs against the operating lever grows less and less until all contact-spring pressure is transferred against the back contact spring or springs. The operating-lever buffer is entirely free of the springs when the handset is on the cradle. As the hookswitch lever swings during the time the plungers are being depressed, the coil spring is lengthening and exerting more and more pull or force. However, the line of force is approaching the center of the lever pivot pin, so the turning torque being applied to the lever reaches a maximum and then starts decreasing.

The "Installer's Hook Lock"

When the housing of a Type 80 Monophone is removed, the hookswitch levers may be depressed and locked so the hookswitch stays in a "handset-on-the-hook" position, just as though the housing were in place and the handset on the cradle. Thus, the Monophone is ready to receive calls and no central-office equipment is held operated. This was accomplished by designing the hookswitch lever and the coil-spring anchoring arms in such a way that the hookswitch lever can be depressed to a position where the coil spring exerts practically no turning torque, but pulls approximately through the center-line of the lever pivot. (The hookswitch is shown in the "hook lock" position in Figure 5). One does not realize the utility of this simple device until he sees a service man trying to balance a pair of lineman's pliers or other weight on the hookswitch levers of a telephone.

Of course, it is essential that the hookswitch restore to operating condition when the housing is replaced on the Monophone. This restoration must be automatic and positive so any forgetfulness on the part of the service man will not result in a "telephone out of order" service call. This is accomplished, as shown in Figure 5, by molding a curved rib into the housing in such a position that as the housing is dropped into place, this rib strikes the hookswitch lever and trips it into operating position. This same rib prevents the lever from moving into "hook-lock" position when the housing is in place. Simple?

The hookswitch is equipped with a clear plastic dust cover, permitting inspection of the contact springs without removing the cover. The operating lever operates the springs through a hole in the dust cover. When the handset is on

the cradle, the lever buffer is free of the hookswitch springs, and a flat spring closes the hole in the cover. Moving the hookswitch into the "hook-lock" position permits easy removal of the cover, which is held in position by a spring and a tongue that fits into a hole in the hookswitch mounting.

The hookswitch contact springs are mounted with their flat surfaces only about 35° off a vertical plane; this, together with the dust cover, ensures most reliable operation.

A simple hook latch is available (see Figure 6) which prevents the hookswitch from operating completely when the handset is removed. The circuit is so connected, and springs so adjusted, that this partial operation connects the receiver (but not the transmitter and dial) across the line. Thus a subscriber on a party line can listen-in without reducing transmission volume if a call is in progress on the line. Depressing a button allows the hookswitch to complete its operation.

"Snap-On" Dial Mounting

The three-point suspension frame to which the hookswitch is fastened provides the support also for the dial. The dial is first fastened by three screws to a mounting plate having bayonet-type lugs; when these engage two pins on the mounting frame the dial is supported by two very heavy bronze springs. To assemble the dial to the base assembly, simply place the dial (on its mounting) on the front legs of the support frame, and press downward against the springs while pushing the bracket up the inclined surface of the front legs. The bayonet lugs of the dial mounting plate pass under studs on the sides of the front legs and when pressure is released the dial and plate are held in place by these studs (see Figure 7). To remove the dial and mounting plate, press downward and slide the plate down the front support legs. When the pressure is released the dial and plate may be easily lifted off the base assembly for inspection of the back of the dial.

Spring-mounting the dial in this way ensures that it will be properly centered in its hole in the housing, that it will be flush with the surface of the housing, and that it will form a dust-tight seal with it. The number-plate is flanged, and an aligning bevel is provided just above the flange. When the housing is assembled to the Monophone (with dial and bracket in place on the front legs of the support frame) the heavy bronze springs force the dial number plate tightly against the housing (see Figure 8).

These springs also greatly lessen the shock to the dial if a Monophone is dropped so it lands on the dial. The springs give, reducing the impact, and then force the dial back into place.

In addition to the extended number-plate and inner arrow plate used to convert the Type 51 dial for use in the Type 80 Monophone, a rear dust-cover has been added. Cords with spade

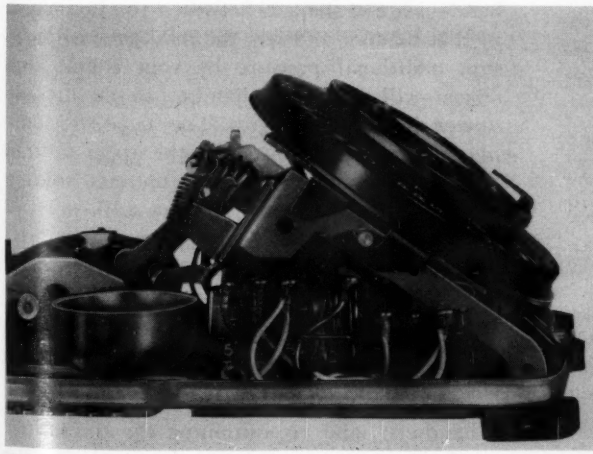


Figure 7. Bayonet mounting of dial is clearly shown in this side view of housing.

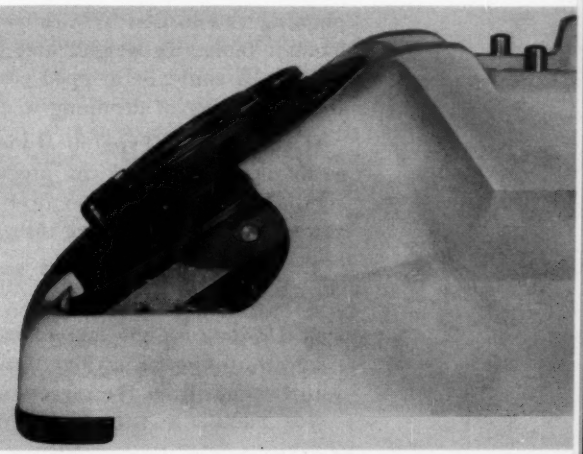
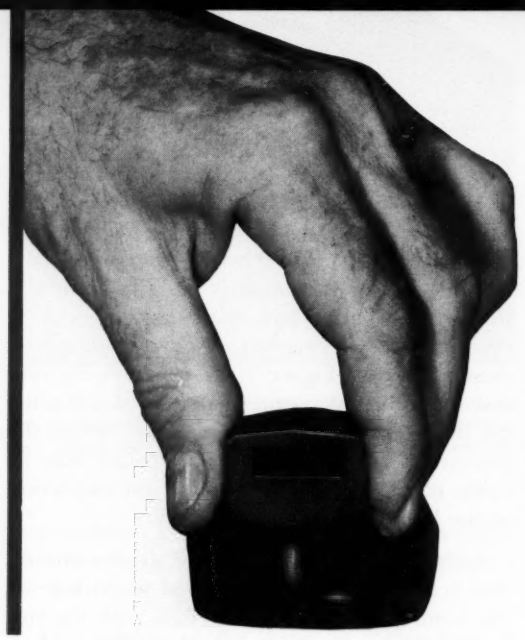
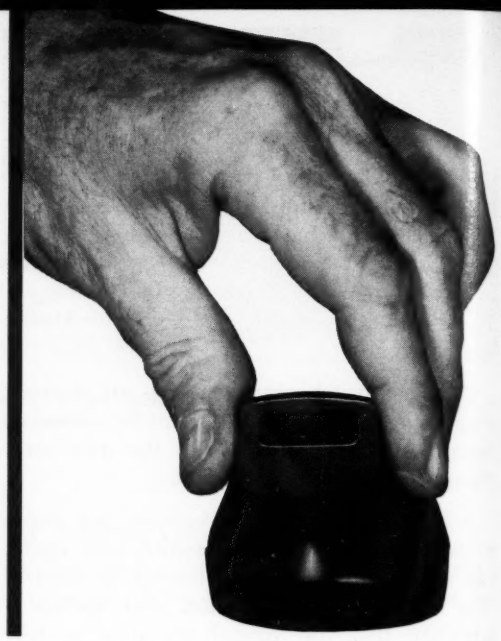


Figure 8. Cutaway view, showing number-plate flange and tapered sides that assure dust-tight mounting of dial to housing.





terminals are fastened to the dial and terminate at screw terminals on the transmission network.

Since a desk telephone must occasionally be lifted and moved about, we provided for this in designing the housing of the Type 80 Monophone, and locating the various components on the base. The surface under the handset is large enough to provide a firm finger-hold, and it has a lip at the edge, to fit the fingers. This finger-grip is at approximately the center of balance of the instrument, so there is no tendency for the Monophone to slip out of the hand.

The Monophone Handset

In designing the handset, we kept in mind the *people* who would be using it. To make telephoning as effortless as possible, we made the handset lighter in weight, and formed its contours so it could be gripped easily and lightly, without danger of dropping it.

If you hold a Type 80 Monophone handset easily in either hand, in proper position for conducting a conversation over the telephone, you will find the following things are true:

1. Your little finger rests on a flat section near the transmitter cup.

2. Underneath the first joint of your second and third finger is a ridge formed by beveling the surface from the center toward each side (see handset at left side in Figure 9).

3. Underneath the first joint of your first finger is the lower corner of the handset near the receiver cup. The portion of your first finger between the first and second joints rests against the flat side of the handset.

4. The ridge down the center of the outside of the handset coincides approximately with one of the grooves formed by partially closing your hand.

5. Your thumb rests along a flat surface on the side of the handset.

All of these things add up to a firm and secure grip on the handset—yet one which is easy and comfortable.

Many people in removing a telephone handset from the telephone cradle, grasp the handset between the thumb and one or two fingers. Some handsets are so shaped that when you hold them in that manner and feel the handset starting to slip, additional pressure by your thumb and fingers will cause the handset to be literally squeezed out of your grip. The Type 80 Monophone handset is shaped with the upper portion of the handset wider than the bottom; holding the handset in the same manner as before and increasing pressure will result in a tighter grip, tending to force the handset *into* your hand and not out. This may be readily seen in Figure 9.

Other important features of the new handset are:

1. Shortening the handset (compared to older handsets), and re-positioning the transmitter relative to the receiver, results in placing the transmitter closer to a person's mouth and

Figure 9. Squeezing the Monophone handset (at left) forces it into the hand; compare this with handset shown at right.

also slightly to one side. This improves transmission by increasing volume and decreasing "blast" due to a person's breath.

2. Molding the handsets without any molded-in threaded inserts (for electrical connections) has a very practical value for the operating company. In handsets with molded-in inserts, accidental stripping of the threads or accidental breakage of a screw necessitates replacing the whole handset handle. In the new Type 80 Monophone handset, only the spring with stripped threads or broken screw need be replaced. The new handset also permits making the connections to the springs outside the handset, and placing the springs in the handset later. The springs fit into either grooves or recesses which hold them in place.

3. Re-contouring the receiver cap resulted in a better seal with the ear, and a more comfortable feel.

4. The use of an additional terminal, about eight inches from the end of one of the wires in the handset cord, eliminated the need for a loose wire in the handset and also the necessity of putting more than one terminal under a screw.

In one important respect molding the handset, in black, was a simpler problem than molding the housing. The handset is, of course, much lighter in weight, and therefore is less likely to break upon being dropped. Coupled with this was the fact that the molded sections of the handset could easily be made as thick as needed to provide adequate impact strength; the wall thickness was not limited by space requirements, as it was in the housing. It was therefore possible to use phenolic materials for molding the black handset and caps by the familiar processes that had been used for our previous telephones.

We felt reasonably certain that by molding the handset on the side and properly maintaining the mold we could minimize the amount of "flash" (the thin projections that are formed when the two sections of a mold do not meet completely), and by proper design treatment could make the flash line serve as a decorative trim line. Buffing or machining would not be needed, and the handset would not only look better but actually *feel* better in the hand. There is an interesting reason for this.

Phenolic molding materials normally used in molding handsets contain wood flour in addition to the molding resin. The molding process results in a layer of cured phenolic resin which covers the wood flour and reduces any tendency to absorb moisture, perspiration from the hands, etc. Buffing or machining exposes this wood flour filler, however, and makes it possible for the wood flour to absorb moisture and perspiration. (You have undoubtedly picked up the handset of an older telephone and felt that it was sticky or gummy; this was probably due to the increased moisture absorption of the exposed wood flour, which helped to hold dirt on the handset). Sometimes, in an effort to protect the wood flour filler, a waxy buffing compound is used but this also results in holding dirt on the handset. The fact is, no finish can be applied to the handset which is as good as the original molded finish.

Design for Color

Since the housing of the Type 80 Monophone was molded of thermoplastics, which are available in a wide range of colors, no re-design was necessary for conversion to color. But the colored handset was a problem; because it was not possible to secure the desired colors in phenolic plastics, it was necessary to re-design the handset for molding in thermoplastics. As previously mentioned, this made it necessary that the wall sections of the handle, and also of the transmitter and receiver caps, be as nearly uniform as possible.

As an example of the problems encountered, see Figure 10. The black phenolic handset at the top of the figure has a tunnel molded in by means of a rectangular core-rod that extends between the plugs that form the transmitter and receiver cavities. This core-rod is removed from the handset after the handset is removed from the mold. Considerable care was necessary in

locating this core-rod and in shaping the transmitter so the rod can be removed. The mold had to be carefully made and curvature accurately controlled; there is only one place the rod can be located and still be removable.

A glance at Figure 10 will show that the thickness of the sections of the black phenolic handset varies considerably and that some sections are very heavy—in fact, at one point the wall is approximately 9/16 of an inch thick. This is permissable for phenolic thermosetting molding; it is totally unsuitable for thermoplastics.

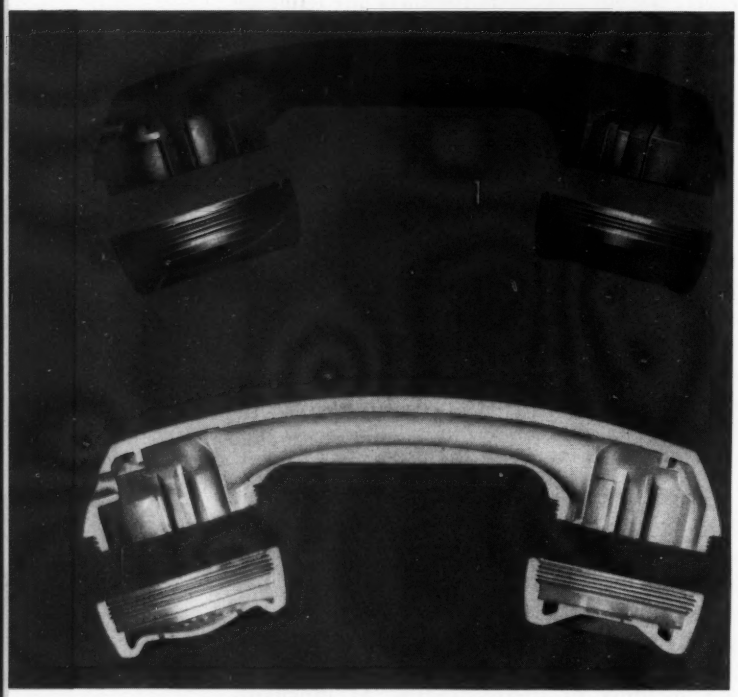


Figure 10. Longitudinal sections of black phenolic handset (top) and colored thermoplastic handset (bottom).

Thermoplastic handsets have been molded in the past but the method used was never very satisfactory. The handle was molded with an open cavity on the inside of the handle (open on the same side as the transmitter and receiver cups). A separate piece was then molded and cemented in place to close the cavity. The resulting handset had very poor strength, and usually poor appearance, due to the cementing.

For thermoplastic molding we designed the handset shown at the bottom in Figure 10. Sections were kept as uniform as possible but, as may be seen, some variation was unavoidable.

By means of careful layout (and several models) we found the tunnel could be made by means of two cores, one fastened to the plug for the transmitter cavity and the other fastened to the plug for the receiver cavity. The plugs for these cavities were so contoured as to reduce the thickness of the sides, the transmitter and receiver being spaced from the sides by adding suitable ribs. Other ribs were so placed as to correctly position the springs.

It was also necessary to redesign the transmitter and receiver caps for thermoplastic molding. A glance at the black phenolic caps in the upper portion of Figure 10 will show that they have some very thick sections. A glance at the injection molded caps in the lower portion of the photograph will show that the sections are much more uniform.

There is much more to this re-design, however, than meets the eye. For example, the receiver must seal tightly against the receiver cap. The space between the receiver and the cap must be carefully regulated, since this serves as a resonance chamber to ensure correct response at certain frequencies. The thickness of the cap at the holes, and the diameter of the holes, must be carefully controlled since these holes form resonant columns of air which control the response at other frequencies. Likewise, thinning the transmitter cap resulted in a change in the resonance chamber between the transmitter and the cap, and we had to compensate for this. (Incidentally, the holes on the cap are so spaced and located that "little Johnny" can't harm the transmitter by poking a pencil into the holes.)

Finally, to further "brighten up" the colored Monophones, we designed a new finger plate, molded of clear plastic. With its chromium-plated escutcheon ring, stainless-steel finger-stop, and number plate matching the color of the Monophone, the new dial adds much to the appearance of the instrument.

The added manufacturing difficulties involved in producing colored Monophones add to their cost, but a Type 80 Monophone in full color, with its colored cords and transparent fingerplate, is a thing of beauty, and well worth the additional cost and effort! One of these instruments is shown on page 1.

To summarize: considerable thought was given to the design of each and every component of the Monophone. We designed the telephone we would prefer to use if we were our own customer. Every useful feature was included that it was possible to put in a telephone which could be sold at a reasonable price. Many of these features, such as the "Walking Handset" the "Installer's Hook-Lock," the self-centering dial, the ringer assembly with its own condenser mounted on the ringer, etc., have never before been available on a telephone.

We also tried to anticipate various "special" requirements for which facilities might be needed. For example, space is provided for three additional hook-switch springs (a total of 8) and for an additional terminal strip required for connections in some circuits. Additional space provided in the housing has also made it possible to add a complete transistor amplifier when desired to make a telephone for the hard-of-hearing.

Yet the development of this instrument will never be completed; the design of its various components is under constant review, and any worthwhile improvement we find will be incorporated into it.

Acknowledgements

The Type 80 Monophone is not the accomplishment of any one man or any few men. It was a team project, involving the coordinated efforts of many people in many departments of our organization. We must acknowledge, too, the contributions of the many telephone operating people who by their comments and suggestions, guided us in the development of this instrument. We hope they are as proud of it as we are!

F. E. WOOD received his BS in Mechanical Engineering from the University of Nebraska in June, 1930, and the next month joined Automatic Electric as a Junior Engineer and Installer. In progressing to his present position he spent several years in Factory and Engineering Inspection, where he learned much about the practical problems of producing equipment to meet the high standards of the telephone industry. Since 1939 he has been Senior Project Engineer, supervising mechanical design of telephones, switches, relays, and dials. An important part of his work is the re-design of existing products to facilitate their manufacture and assure customer satisfaction.

THE TYPE 45

As a Numerical Single Motion Stepping Switch of Large Capacity

By KURT MULLERHEIM
Patent Agent, Automatic Electric Company

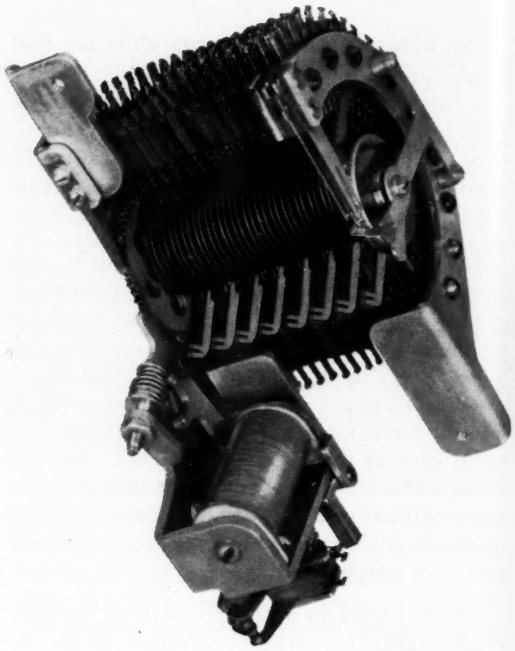


Figure 1. Type 45 rotary switch with 16 single-ended wipers, as used in Navy switchboards.

1. Introduction

Since its first appearance shortly after the war, the Type 45 rotary switch (see Figure 1) has proved its worth as a high-speed switching device of extraordinary durability, flexibility, and ease of adjustment in a great variety of applications. A detailed description of this switch will be found in an earlier article.[1]

Stated briefly, the Type 45 switch is a 26-point rotary switch of the indirect-drive type—i.e., its wipers are advanced during *release* of the armature. The Type 45 rotary switch is designed to operate self-interrupted at speeds up to 70 to 75 steps per second, and its bank will accommodate up to 16 levels. As the bank is semicircular, the switch can be arranged to sweep over 52 circuits consecutively, by using single-ended wipers spaced 180 degrees apart and traveling over separate levels, as shown in Figure 1. In addition to the interrupter springs required for self-interrupted operation, "off-normal" springs may be provided.

In the telephone field proper, numerous applications come to mind in which this rotary stepping switch is giving outstanding service as a hunting switch—e.g., a line or trunk finder, a director hunter, or a sender, cord circuit or link finder in manual or automatic toll boards. In addition, the Type 45 switch has established a lasting place for itself as a numerical switch of small or medium capacity. For this new switching tool is used not only as a finder but also as a connector switch in such modern Automatic Electric switchboards as the 20 and 40-line Type 47 P-A-X's and Type 48 C-A-X's.[2]

More recently the new rotary switch has made its first appearance as a large-capacity numerical switch in a 100-line automatic exchange which was developed and manufactured by Automatic Electric Company for shipboard use on behalf of the U. S. Navy (see Figure 2). The particular exigencies of this application, which involve potential exposure of the switching equipment to violent acceleration forces, called for switch of simple and compact design with a largely shock-resistant driving mechanism. Thus, the choice fell on the Type 45 rotary switch, which is mechanically self-locking in any of its positions.

As this switch can be equipped with up to 16 levels and with single-ended staggered wipers, the accommodation of as many as 100 lines in

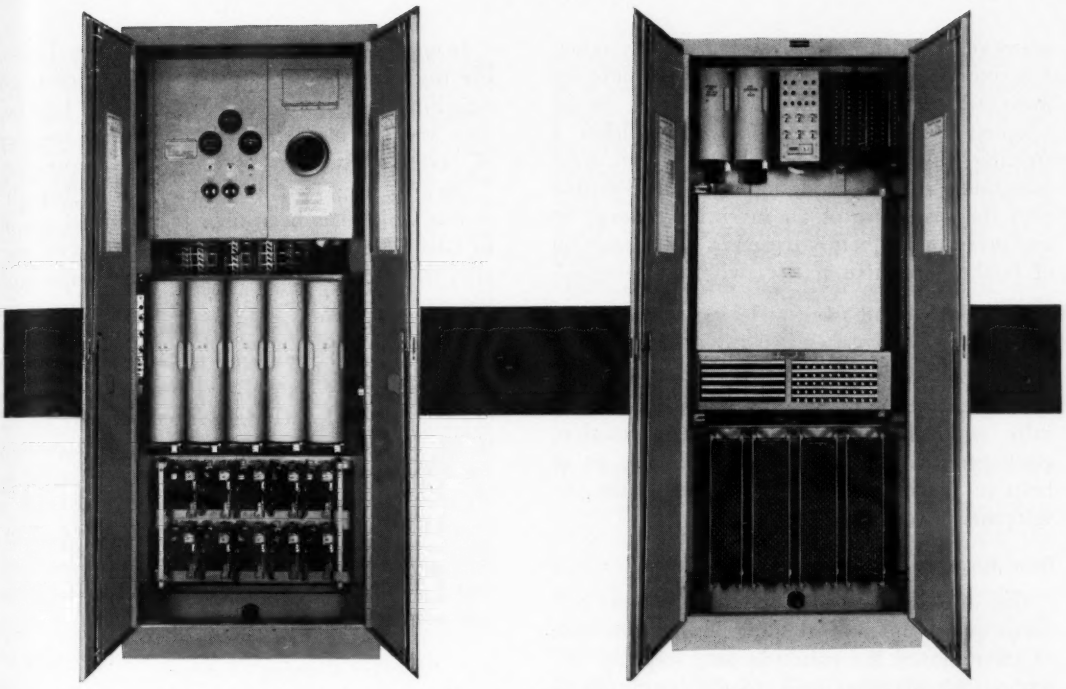


Figure 2. Front and rear views of typical Navy switchboard, using Type 45 rotary switches as finders and connectors. The five finder-connector links are shown at the bottom in the rear view.

the bank of this switch posed no problem in itself. From a circuit standpoint, too, it might appear at first glance that with a rotary stepping-type connector for 20 or 40 lines already available, it would be a matter of relatively simple circuit expansion to similarly effect the numerical selection of any one out of 100 outlets. Actually, however, the circuit problem becomes considerably more complex as the step is taken from 40 to 100 lines.

In a small P-A-X—for instance, the 20-line Type 47A—the call numbers can readily be chosen so that the switch is advanced under the direct control of the dial (i.e., on a one-step-per-impulse basis) directly to the beginning of the desired group of bank contacts. A typical numbering scheme in such a case is 3-8, 91-99 and 901-905—switch positions 9 and 19 being unused and serving as waiting positions (1 and 2 are also, of course, unused). However, as there is obviously a limit to the number of digits that may be used in a given call number, this "adding" principle cannot be employed where, say, ten groups of lines are involved.

Another principle is used in the Type 48 C-A-X. A given one of a number of marking relays is operated at the end of the tens digit, and the switch then started on an automatic stepping action which positions it adjacent to the beginning of the selected group, in readiness for the receipt of the units digit. Where there are as many as 10 tens groups to be served, however, the short interval between the end of the tens digit and the beginning of the units digit is insufficient to assure that even a high-speed single-motion switch, such as the Type 45, will always be advanced to a point in the bank adjacent to one of the high-numbered groups, in time for the second digit. This situation is further aggravated in the case of a selector, because in that case the switch must have completed not only its group-selecting action but also its trunk-hunting operation, before the next digit arrives. Circuit-wise, then, the problem involved in using the Type 45 switch for 100 lines was primarily that of getting this rotary stepping switch to "skip over" a considerable number of unwanted contacts within the stiff time limits imposed by the inter-digital pause.

In tackling this problem, Automatic Electric engineers built upon a series of earlier Automatic Electric inventions extending back over

many years which were developed to solve other, but similar, problems. The story of the development which led finally to the circuit design adopted for the "Navy Board" furnishes a striking illustration of how in a modern, well-integrated research and development organization the disclosure of an inventive concept by one inventor frequently triggers a chain reaction of further inventive activity within the organization.

2. The Problem In Perspective.

A brief outline of past proposals for numerically controlling multi-contact, single-motion, electro-mechanical stepping switches may be of help in placing in proper perspective the development work treated herein.

2a. Switches with Long and Short Steps.

One of the earliest proposals involved the provision of two different stepping mechanisms. One of these moved the switch in long steps of, say, ten contact divisions each, to the beginning of the desired group; the other then positioned the switch in short steps on an individual line within this group. A system employing switches of this type was commercially used in Europe on a limited scale, but today such systems are probably of historical interest only.

2-b. Digit Storage.

Up to this point it has been tacitly assumed herein that the digital impulses from the subscriber's calling device are dialed directly into the numerical switch. However, there are in existence a number of systems in which the time problem involved in positioning a large-capacity numerical switch of the rotary stepping type has been circumvented by the expedient of "digit storage".

In one form of systems of this kind, the series of impulses received from the subscriber's dial are stored in "register" equipment at the call-originating point, i.e., the calling office; this equipment then re-transmits these impulse series (after translation, if necessary) to the numerical switches of the various ranks, but with a wider spacing between groups, to allow for the "setting" time required by the individual rotary switches. These systems thus employ what amounts, in effect, to a "delay-in-dialing" method.

In another form of systems of this general class, the digit storage takes place at the individual switching stages – usually in "marker" switches that are associated in common with a number of "talking" switches of the rank in question. Typical of this kind of system is the "bypath" system which has been used to a limited extent in Great Britain. This system employs two parallel trains of rotary stepping switches—the talking train (called the "path") and a control train (called the "bypath"). The switches in the talking train are not expected to keep up with the digital impulses transmitted from the subscriber's dial. Instead, each digit is temporarily stored in the bypath equipment of a given stage, and the associated talking switch is then allowed to set itself at its own pace in accordance with a "marking" received from the bypath equipment. The completion of the talking train therefore lags behind that of the control train and thus lags considerably behind the dial.

2-c. "Marker Chasing" Scheme.

A notable offshoot of the conventional technique of digit storage by means of markers is the "Marker Chasing" scheme. A commercially successful arrangement of this kind was proposed by Barnay as far back as 1925 (U. S. Patent 1,566,474). In Barnay's arrangement the bank of the marker switch, which is of standard design, is connected with a bank of the rotary-type talking switch by a number of separate group-marking leads, one at the beginning of each group of lines or trunks; when the talking switch reaches a marking lead that is marked by potential over the wiper of the marker switch, a test relay operates to stop the automatic advancement of the talking switch. The feature of interest in the Barnay arrangement is that the talking switch is started on its automatic rotation immediately after the marker switch has taken its first step in response to the first dial pulse received. As a result, the talking switch executes a "follow-up" movement with respect to the marker switch during the receipt of the impulse series, and is never far behind it. If the talking switch is fast, however, it is prevented from over-running during this "group-skipping" process, by the operation of the aforementioned stopping relay in any position of coincidence of the two switches.

At this point it may be noted in passing that other patent proposals (e.g., British Patent 196,990) of the type allowing for concurrent automatic advancement of the talking switch with an impulse-controlled marker switch were made at an early date; in these, the marking of the desired group is effected on an "absence-of-potential" rather than a "presence-of-potential" basis. This makes for a faster stopping action since it does not require the operation of a test relay for arresting the switch. However, if "absence-of-potential" searching is used, provision must be made for maintaining potential on the marking leads already swept over by the marker switch, so as to insure proper group positioning of the talking switch even though the latter lags behind the marker switch. For this reason it was proposed that the marker switches be equipped with a trailing or arc-ended wiper; it is probably because of the special switch construction required by these arrangements that they failed to gain commercial acceptance.

3. Summary of Requirements of New Application.

When Automatic Electric's circuit designers set out on their recent circuit-development work, they realized that the weaknesses of the above prior arrangements had to be avoided. This meant that these designers had to come up with a reliable, self-contained, connector or selector circuit for an electromagnetic, single-motion stepping switch that would meet the following fundamental requirements:

(1) The circuit was not to require a special switch design, nor was resort to be had to the conventional expedients of register or marker switch control: trunking was to be done along straightforward Strowger principles.

(2) The switch was to execute its group-skipping operation, directly to the beginning of the desired outlet group, concurrently with the receipt of the dial pulses; all delays incident to this operation (as would be caused, for example, by the use of interrupter or test relays) were to be eliminated.

(3) To meet the requirements of straightforward Strowger trunking, groups of 10 outlets each were to be provided; to meet the timing requirement, the switch would have to be capable of skipping a group, and moving to the next one, in the time between two impulses. Using the Type 45 switch (which, in a 46-volt d.c. self-interrupted circuit steps at a rate of approximately 70 steps per second), this requirement would be met with an ample safety margin if the switch were not required to make more than 5 or 6 steps in skipping a group. At the nominal dial speed of 10 impulses per second, a stepping speed of only 50 steps per second is required to advance the switch wipers 5 steps in the time (100 millisecond) corresponding to each numerical impulse.

4. Development Based on Previous Circuits.

Automatic Electric's development engineers were fortunate in that a circuit meeting the above three fundamental requirements had been thought up at a much earlier date by a team of Automatic's circuit designers. This groundwork was laid in United States patent 1,903,207 which issued to John Wicks, et al, in 1933. The circuit arrangement according to this patent (which, by way of example, is shown in Figure 3, as applied to a selector) satisfies the above-mentioned basic conditions by the skillful refinement of a group-selecting principle which had made sporadic appearances in patent literature but had apparently found no commercial acceptance prior to that time The group-selecting method used by Wicks is "flip-flop" skipping.

4-a. Multi-Level Switches with "Flip-Flop" Skipping of Two-Level Groups.

In the "flip-flop" skipping arrangement, according to the Wicks patent, five outlets of each group appear in one set of talking and test levels of the talking switch, and the five other outlets of the same group appear in the corresponding switch positions of the other set of levels (see Figure 3). The switch also has a group-skipping control wiper and bank, GC, which is common to both sets of levels. Flip-flop control conductors R and S are multipled to alternate sets of five contacts in this bank, and during the group-selecting operation of the switch (relays B and C operated) self-interrupter circuits which respectively extend over these two control conductors, the corresponding sets of GC bank contacts and the GC wiper to the motor magnet MM of the talking switch, are alternately ener-

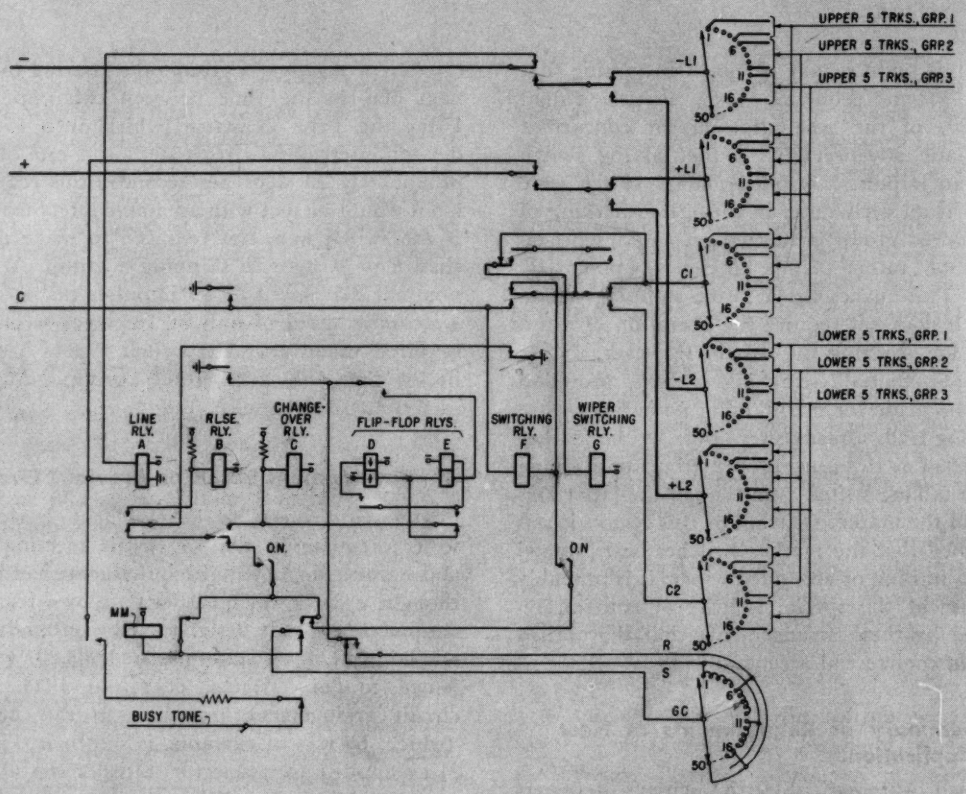


Figure 3. Circuit of early selector switch using "flip-flop" skipping of groups on two levels.

gized at the make-before-break contact of relay D. Relays D and E are a pair of pulse-alternating relays controlled by the break contact of line relay A. Thus relay D changes its condition on each release of the impulse relay, and as a result the selector switch is advanced from its last position to position 1 upon receipt of the first dial pulse, then from position 1 all the way to position 6 upon receipt of ehe second dial pulse, and so on. In this manner the switch is stepped (concurrently with the receipt of the impulse series) over the positions corresponding to non-wanted trunk groups, directly to the first or start position, e.g., 6 or 11 or 16, etc., of the desired group; at this point energization of switch magnet MM is no longer possible because of absence of stepping ground. It will be appreciated that for the same reason the switch is prevented from getting ahead of the dial pulses at any time, inasmuch as the D-relay does not change its condition in the "make" periods of the numerical pulses. On the other hand, the switch may lag to a certain extent behind the pulses that make up the digit.

At the end of the digit, change-over relay C releases, to initiate an automatic trunk-hunting action in both test levels C1 and C2, under the control of relays F and G. This hunting action also is of the absence-of-ground searching type. If an idle trunk is found, this automatic stepping action is arrested and switching relay F operates in series with magnet MM (with wiper-switching relay G operated or not, as the case may be) and the connection is switched through to the succeeding switching stage in the usual manner. If all trunks in the selected group are busy, the switch reaches the position corresponding to the first two trunks of the following group and in this position switch magnet MM is permanently energized over a circuit including the GC wiper and the second break contact from the bottom of relay C. This prevents further stepping action, and causes busy tone to be returned to the calling subscriber.

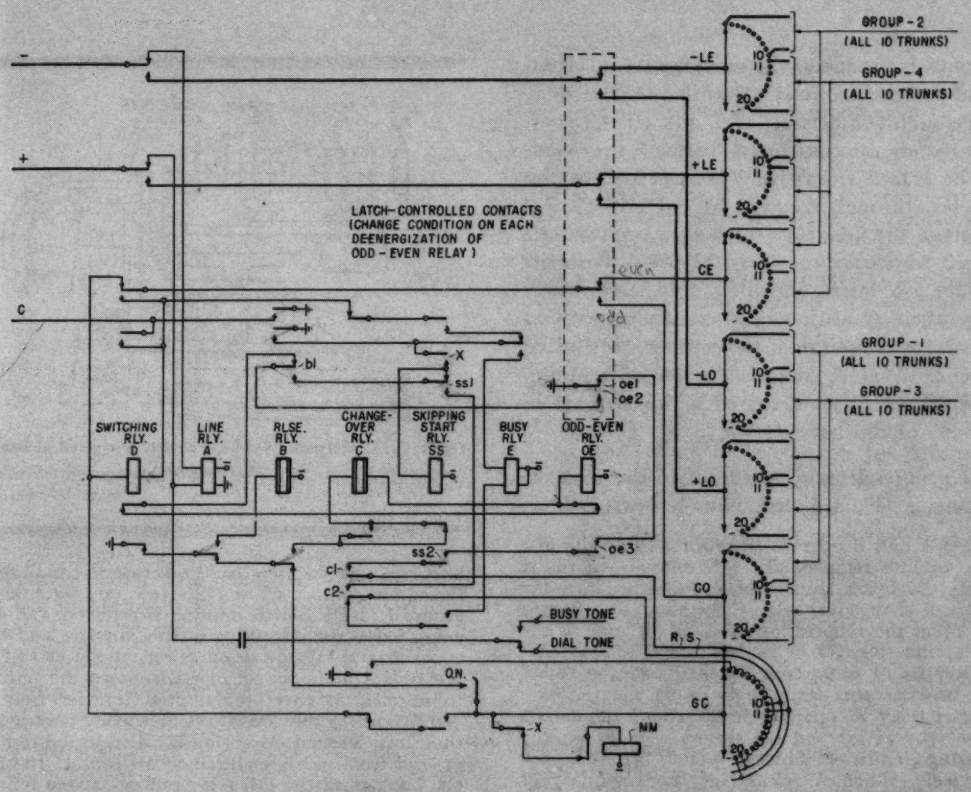


Figure 4. Circuit of later switch with "flip-flop" skipping of groups on one level.

4-b. Multi-Level Switches with "Flip-Flop" Skipping of One-Level Groups.

The next step toward the required circuit was made in a proposal which came from Automatic's Belgian affiliate, Automatique Electrique, S.A., in 1947. This scheme permitted straightforward assignment of any one outlet group to a single level of the switch—i.e., it avoided the splitting-up of each individual group as between odd and even levels. Thus it eliminated double trunk-hunting when the switch was used as a selector, and made it possible to advance the switch one step on each impulse in the units digit, in the usual manner, when used as a connector. The speed and reliability of the overall switch operation were enhanced, yet no greater speed was required of the switch mechanism proper.

In effect, these improvements are obtained by using two consecutive pulses of the group-selecting series for the flip-flop skipping of a given 10-position outlet group; alternate pulses of the group-selecting digit are absorbed (except that wiper switching is made dependent on whether this digit is odd or even). An "odd-even" relay of modern design is used to effect both the group-skipping and wiper-switching operations under the control of the dial pulses.

Referring more specifically to Figure 4 (which is a "selector version" of this proposal), the switch again has two sets of talking and test levels, but in this case all the even groups of trunks are assigned to one set, and all the odd groups to corresponding positions in the other set. Two flip-flop conductors, R and S, again are multiplied in alternate fashion to contacts in the common control bank GC, but this time conductor R is connected to the contacts corresponding to the first position of each group, and conductor S to the contacts corresponding to the last position of each group, while the intermediate contacts of all groups are multiplied directly to ground through a make contact of change-over relay C. The energizing circuit

for control conductor R may be traced from ground at break contact *oe1* of "odd-even" relay OE, through contacts oe3, ss2, and c1; the energizing circuit for control conductor S may similarly be traced from make contact oe2 of the OE relay, through contacts b1, ss1 and c2. All contacts of the OE relay (including contacts oe1 and oe2 which are shown in Figure 4 above its winding) are latch-controlled, and accordingly change their condition only on *de-energization* of this relay as indicated; the contacts (including contact oe3) which are shown below the winding of the OE relay are actuated as in the case of any relay of ordinary design.

The group-selecting operation of the selector, assuming a "4" is dialed, is as follows:

Relays A and B operate on seizure. Upon the first release of line relay A, the OE relay is energized through the break contact of A in series with the winding of changeover relay C, without effect at this time. Upon the reoperation of A at the end of the first impulse, the OE relay is de-energized so that its upper set of contacts is actuated and the "odd" set of switch wipers accordingly connected up. Skipping-start relay SS operates from ground at contact oe2, thereby at ss2 and ss1 closing a point in the energizing circuits of "flip-flop" conductors R and S, respectively. When A releases at the beginning of the second impulse, OE is re-energized, again without effect. Responsive to the re-operation of A at the end of the second pulse, the OE relay is de-energized and the upper set of contacts of this relay restored to normal, transferring the circuit to the "even" set of switch wipers.

Up to this point, no circuit for switch magnet MM has yet been established. Only when oe3 closes incident to the *third* energization of OE upon the third release of line relay A, can the following self-interrupter circuit for magnet MM be closed by way of conductor R: ground, contacts oe1, oe3, ss2, c1, conductor R, GC-wiper in position 1, "X" contact of relay E, self-interrupter contact, MM, battery. The switch is thus stepped to position 2, and in positions 2 through 9 the self-interrupting action of the switch is maintained from ground at the bottom make of C, independently of the dial pulses. The switch is thus advanced into position 10.

As soon as OE is de-energized upon re-operation of A at the end of the third impulse, ground is removed from conductor R at oe3. At the same time the upper set of contacts of OE again is actuated so that the odd set of wipers is connected up and the following interrupter circuit for magnet MM closed via conductor S (assuming the switch has already reached position 10): ground, oe2, b1, ss1, c2, conductor S, GC-wiper in position 10, "X" contact of E, self-interrupter contact, MM, battery. The switch wipers are thus advanced into position 11.

It will be noted that position 11 forms the beginning of both groups 3 and 4 and that if no further impulse were to follow, trunk group 3 would have been selected in view of the actuated condition of the upper contact set of OE. However, since in this assumed case a fourth impulse is received, OE is re-energized at the beginning of this impulse, and when relays A and OE are de-energized at the end of this last pulse, the upper set of OE contacts are returned to normal, to effect the desired transfer from the "odd" back to the "even" set of wipers. Group 4 has thus been selected. Attention is called to the fact that ground from oe2 is maintained on contact 10 of the GC bank until the OE relay restores at the termination of fourth impulse as just described. It is for this reason, and also by reason of the direct-ground strapping of intermediate GC bank contacts 2-9, that if more impulses were to follow, the switch would be allowed a time interval equivalent almost to two dial pulses (such as 3 and 4) for skipping over a set of 10 switch positions.

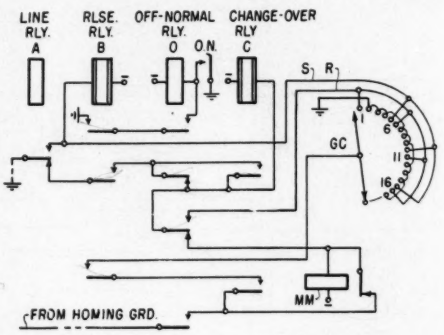


Figure 5. Circuit with "flip-flop" circuits energized at impulse-relay contacts.

After the release of change-over relay C, "absence-of-ground"-type trunk-hunting in the selected group (4) takes place in the usual manner, in this case over "even" test wiper CE. When an idle trunk in this group is found, the automatic stepping operation of the switch is stopped, due to absence of ground, and switching relay D is operated in series with motor magnet MM, to switch the connection through to the next switching stage. If all trunks in the selected group are busy the switch reaches position 20, to which the last trunk of group 4 is connected, and in this position busy relay E is operated from ground by way of the GC-wiper and the S-conductor to return busy tone to the calling party.

4-c. Energizing "Flip-Flop" Circuits at Impulse-Relay Contacts.

Close upon the heels of the "Antwerp" circuit, two new selector circuits were suggested by two different members of Automatic Electric's engineering staff in Chicago. An interesting feature of the first of these proposals (see Figure 5) is that the self-interrupter circuits extending over flip-flop leads R and S to the stepping magnet of

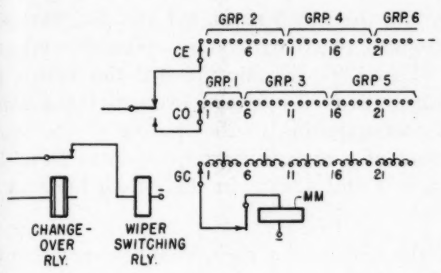


Figure 6. The group-staggering principle.

the selector switch are energized directly at contacts of line relay A—again in such a way that this talking switch is immediately advanced by the dial impulses to the beginning of the desired group. This eliminates delays in group-selection caused by the operate time of the intermediate flip-flop devices used in the circuits previously described.

As far as the assignment of the trunk groups in the switch banks is concerned, this circuit follows the precedent of the Wicks patent—i.e., one half of the trunks of each group appear in the upper set of talking and test levels, and the other half in the corresponding positions of the lower set. However, the wiring of the common GC bank differs from that of Wicks in that the R lead is multipled to the GC contacts in the first position of all groups and the S lead multipled to the GC contacts in the last position, while all the intermediate GC contacts are strapped directly to ground, as shown.

Assuming for the purposes of illustration that the digit dialed into the selector is 2, the group-selecting operation of the switch is as follows:

On the first release of A in response to the first dial pulse, MM is operated in multiple with change-over relay C, through break contacts of off-normal relay O. When the line relay subsequently reoperates at the end of this pulse, MM is de-energized so that the switch is advanced from its last to its first position and relay O operated from off-normal contact O.N. On the second release of A, incident to the receipt of the second impulse, the following self-interrupter circuit is closed for switch magnet MM: ground, break contact of A, make contacts of B, C and O, control conductor R, GC wiper in position 1, lower make contacts of B and C, self-interrupter contact, MM, battery. The switch is thus stepped into position 2, and thence (due to the ground-strapping of GC contacts 2-4) all the way to position 5. Upon the reoperation of A at the end of the second dial pulse, the following interrupter circuit for magnet MM is closed by way of the S lead with the switch in position 5): ground, make contact of A, conductor S, GC wiper in position 5, lower make contacts of B and C, self-interrupter contact, MM, battery. The switch is thus stepped into position 6, which accommodates the first two trunks of the desired group (2). Upon release of C at the end of the digit, a double trunk-hunting operation in this group is initiated in a manner not further illustrated in Figure 5.

Note that because of the direct control of flip-flop leads R and S at the contacts of line relay A, the switch is stepped off the first position of any group to be skipped at the earliest possible moment, viz., immediately upon release of the impulse relay. The switch thus has ample time to step, at its own pace, over the intermediate switch positions. and is then safely stepped off the last position (such as 5) of the group—provided only that it reaches this position some time prior to the release of relay A at the beginning of the next pulse.

4-d. Group Staggering

The "Antwerp" circuit (Figure 4) showed one way of accommodating all ten outlets of any given group on the same level of a multi-level switch, and allowing the switch a time interval roughly equivalent to two dial pulses for skipping any set of 10 switch positions. Figure 6 schematically illustrates another strikingly simple arrangement which reaches a similar result without requiring absorption of every other pulse of the group-selecting digit. This is accomplished by merely assigning the individual "odd" groups in the "odd" banks of the switch in staggered fashion with respect to the corresponding "even" groups in the "even" banks—preferably so that the ends of the "odd" groups approximately coincide with the mid-points of the "even" groups, as shown—and by letting the "odd" or "even" character of the received digit decide which of the two sets of wipers is to be made effective. This arrangement makes it possible to control the "group-skipping" movement of the switch in sets of five steps instead of ten, which tends to enhance the uniformity of switch movement. Moreover, regardless of whether the last digit received is odd or even, only five switch positions must be skipped on the last restoration of the line relay, whereas in the

"Atwerp" scheme a final set of 10 switch positions must be skipped after the last release of the impulse relay, if the last digit is odd.

4-e. Multiple Use of Circuit Elements

The selector circuit shown in full in Figure 7 incorporates a modified version of the impulse relay control of Figure 5, and it carries forward the group-staggering arrangement of Figure 6 by applying it to a switch with "flip-flop" control of its self-interrupter circuits. This circuit is remarkable for the extent to which multiple use is made of relays, and also of switch wipers and banks. It includes the following notable features:

(1) The flip-flop conductors are under the control of a break contact of the impulse relay and are also under the control of a "lock-pulse" relay which, in turn, is controlled jointly by this break contact and the GC wiper and bank of the switch. The result is that the break period of the individual dial pulses need only be long enough to "cock" the lock-pulse relay. Yet, in this circuit, too, over running of the pulses by the switch is made impossible. Use of the line-relay make contact as a means for controlling the group-skipping movement of the switch has been eliminated in this circuit.

(2) By means of a rather interesting flip-flop conductor arrangement, the circuit makes it possible to use the GC wiper and bank for two further control purposes, viz.:

(a) For the control of the wiper-switching relay at the end of the digit, as required by the group-staggering principle—i.e., depending on whether the value of the digit was odd or even.

(b) For limiting the extent of the trunk-hunting movement to the selected group without resort to separate overflow positions —and this in spite of the fact that the odd and even groups overlap each other in the bank of the switch.

This circuit utilizes a total of four flip-flop leads, here designated RO, SO and RE, SE. Generally speaking, lead RO is multipled to the GC bank contacts in the first four, and lead SO in the fifth, position of odd groups, while lead RE is multipled to the GC-contacts in the first four, and lead SE in the fifth, position of even groups. During the group-skipping movement of the switch—i.e., during the receipt of the digit —the two R leads, RO and RE, are coupled together at make contact c2 of the change-over relay, and the two S leads, SO and SE, likewise are coupled together, by way of break contacts ws3, t4 and t6. In this manner the switch is flip-flop controlled in sets of five switch positions each, corresponding to the spacing of the start positions of consecutive groups such as 1 and 2, 2 and 3, 3 and 4, etc., in the switch bank as a whole.

At the end of the digit, change-over relay C releases, thereby at c2 separating the RE from the RO conductor; if the digit dialed was odd, "transfer" relay T alone operates over the GC-wiper and the RO conductor; if the digit was even, "wiper-switching relay" WS operates over the GC wiper and the RE conductor, in turn operating T at ws5. Consequently, the coupling between the flip-flop leads is now rearranged as follows:

(a) If the digit was odd, T alone is operated and conductors RO, SO and RE are coupled together via ws3, t5 and t9, while SE is left dead.

(b) If the digit was even, both WS and T are operated and conductors RE, SE and RO are coupled together by way of t5, ws4 and t9, while SO is left dead.

During trunk-hunting the arrangement is such that the self-interrupter circuit for the switch magnet extends over the selected test bank and wiper and the GC bank and wiper in series. Therefore, if all trunks in a selected odd group are busy, the switch is automatically arrested in the 10th position of the group in which the GC wiper engages the open SE conductor; if all trunks in a selected even group are busy, the switch again is stopped in the 10th position of this group, because in this position the GC wiper engages the open SO lead.

Restricted service is provided in a simple manner by means of a separate control wiper and bank SC, which is also used for overflow metering. Ground for the above-described operation of relay T or WS is derived from the incoming EC lead, which is connected to the SC wiper through a rectifier and contact c6. Therefore, if no ground is encountered by the SC wiper at the end of the digit as an indication

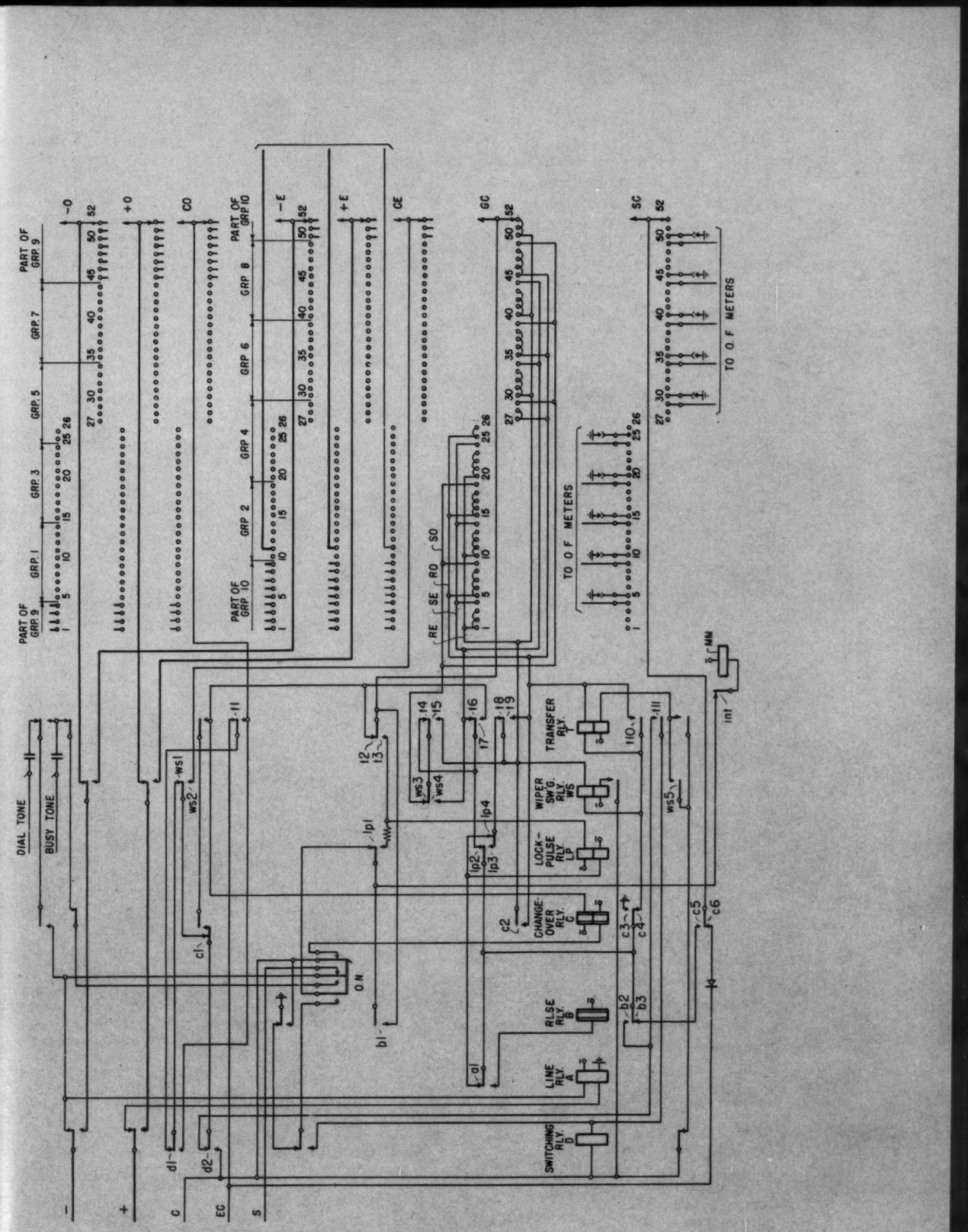


Figure 7. Selector circuit combining group-staggering and "flip-flop" control.

that the selected group (say inter-office trunk group "0") is a restricted group, and if, furthermore, ground is not connected to the originating end of the EC lead as an indication that the calling party is not privileged to make such calls, then there is no ground available for the operation of relay T or WS. Under this condition no further automatic stepping action of the switch takes place, and busy tone is returned to the calling party by way of break contacts of T and C.

Before some of the more important circuits involved in the operation of this selector are traced in detail it should be mentioned that in the arrangement of the Type 45 rotary switch underlying this circuit the wipers, 16 in number, are single-ended and connected together in pairs, the wipers of each pair being staggered 180° relative to each other, in the conventional manner. In order to more clearly illustrate the assignment of the various groups in the switch banks, the wiper-staggering arrangement has been brought out in this schematic straight-line presentation by showing the two wipers of each pair vertically in alignment but showing the two levels of bank contacts associated with these wipers horizontally displaced by 26 steps with respect to each other; in reality, of course, all levels are mutually aligned.

It will further be noted that an extra pair of trunks is shown connected, both in the 26th and in the 52nd position of the switch. This is made possible by the design of the Type 45 switch, which provides an additional complete set of bank contacts in these positions—i.e., at a point diametrically opposite the location of the wiper collector springs. It thus became possible to equip groups 9 and 10 with twelve instead of ten trunks each, as shown. Moreover, due to the fact that each of these groups "spills over" to the beginning of the contact bank, absorption of the first dial pulse is not required from the standpoint of group selection; in response to this first impulse the switch merely skips the corresponding positions of groups 9 and 10 and at the end of this impulse is thus positioned at the beginning of group 1. In this respect the present selector circuit, in part, follows the precedent of the actual circuit which was partly shown in Figure 5.

The operation of the selector (Figure 7) will become clearer from the following description, in which some of the key circuits of this switch are traced in full:

Relays A, B and C operate on seizure. Assume a "2" is dialed into this circuit. Upon the first release of A, relay LP operates from ground at c3 by way of a1 and its lower winding, and MM is operated in the following self-interrupter circuit: ground, c3, thence over a1 and 1p4 (or, subsequent to the operation of LP, directly over 1p3), and via t8, RE lead, GC wiper in normal position 52, b1, int, MM, battery. The switch steps to position 1. After the operation of the O. N. springs, C is held in parallel with MM, over t2 and its upper winding. LP also locks in parallel with MM, via 1p1. These two locking circuits, as well as the self-interrupter circuit, are maintained in switch positions 1-3 so that the switch is automatically stepped into position 4 regardless of whether or not A reoperates in the meantime. LP releases when the circuit of its lower winding is opened at a1 upon the reoperation of A and when, in addition, the circuit of its upper winding is broken incident to the switch stepping off position 3. With LP released the switch is advanced from position 4 to 5, through the following self-interrupter circuit: ground, c3, 1p2, t6, SE lead, GC wiper in position 4, b1, int, MM, battery. Since, during the receipt of the digit, lead RO is coupled to RE and lead SO to SE, the switch is in a similar manner advanced, in response to the second impulse, from position 5 to 9 and then from 9 to 10, which is the first position of the desired group 2.

At the end of the digit, C releases, disconnecting the RO and RE leads from each other at c2. Due to the fact that the digit dialed is even and that the GC wiper accordingly engages the RE lead, the following circuit is closed for wiper-switching relay WS (provided the call is not subject to restriction):

Ground on EC, t1, d1, ws1, c1, d2, b2, c4, upper winding of WS, RE lead, GC wiper in position 10, b1, int, MM, battery. WS, only, operates in this circuit, among other operations substituting the even for the odd set of wipers and operating T at ws5. Both WS and LP lock over their lower windings. T short-circuits the operating windings of T and WS at t10 and t9; couples leads RE, SE and RO together via t5, ws4 and t9; and at t11 connects the right-hand winding of switching relay D to the trunk-hunting circuit. This latter circuit may now be traced as follows: ground on the test lead of the first trunk in selected group 2 if this trunk is busy, even test wiper CE in position 10, ws2, c1, d2, b2, c4, t10, t9, RE lead, GC wiper in position 10, b1, int, MM, battery. LP operates in parallel with MM, via t3 and its upper winding, to supervise the trunk-hunting action of the switch. The switch thus steps into position 11, and this automatic stepping action as well as the last-mentioned circuit of relay LP are maintained in positions 11-13 by way of lead RE, in position 14 by way of lead SE and in positions 15-18 by way of lead RO, until an idle trunk in group 2 is found. As soon as this is the case, absence of ground on the corresponding test lead causes LP to be released, the advancement of the switch to be stopped and the short-circuit around the winding of switching relay D to be removed. Accordingly D operates in series with MM from ground at the top make of B, thereby switching the connection through in the usual manner and permitting A, B and T to release.

If all trunks in the selected group are busy, the self-interrupter circuit of MM and the circuit of LP are broken (due to the GC wiper in position 19 engaging open lead SO), and upon release of LP, relay C reoperates over the following circuit: ground on the test lead of the last trunk of group 2, test wiper CE in position 19, ws2, c1, d2, b2, 1p2, t7, upper winding of C, battery. C locks at the make of its make-before-break contact to ground at c3, and at its top make contact connects busy tone to the calling end. Upon release of the switch train by the calling party, the overflow meter of group 2 is momentarily operated, during the release of C subsequent to that of B, over the following circuit: ground, c3, b3, c5, SC wiper in position 19, O.F. meter (not shown) of group 2, battery.

5. The Navy P-A-X Circuit

The circuit proposals discussed in the preceding sections set the stage for the circuit shown in Figure 8, which illustrates the basic elements of the party-line connector for the Navy P-A-X, as far as these elements have a bearing on the subject matter of this article. (The connector circuit actually used in this board provides for certain additional services not illustrated in Figure 8, which were later worked into the circuit to meet specific requirements of this installation. The inclusion of these special services necessitated the provision of two additional wipers so that the connector switch actually employed has a total of 16 wipers as shown in Figure 1 instead of only 14 wipers as indicated in Figure 8.)

This circuit employs group staggering in conjunction with a further modified version of impulse relay control of flip-flop circuits. The following are its outstanding features:

(1) The connector uses the wiper and bank, A3, of an auxiliary rotary switch of miniature type for purposes of party selection. Another wiper and bank, A2, of this station selector switch is used for switching the circuit from one wiper set to the other, depending on the odd or even character of the digit dialed, thereby to facilitate group staggering; because of the ready availability of the station selector switch, a further wiper and bank, a1, of this switch is used as an auxiliary switching element for insuring alternate energization of the two flip-flop conductors, R and S, during the receipt of the group-selecting (i.e., the "tens") digit. This station selector is a Type 44 11-position stepping switch with indirect drive, which requires no more mounting space than a single telephone-type relay as shown in Figure 9. The stepping magnet of this switch is designated MM44 in Figure 8.[3]

(2) The connector switch itself is a Type 45 rotary switch having a stepping magnet MM45. For the tens positioning of this switch two flip-flop conductors R, S are provided. One of these two conductors, R, is multipled to the GC bank contacts of this switch, corresponding to the start positions of all odd tens groups of lines with the exception of the first, while the other conductor, S, is multipled to the GC bank contacts corresponding to the start positions of all even tens groups of lines except the last (Note: "Start" position, in this case, means the position immediately ahead of that accommodating the first subscriber's line of the group in question). The intermediate contacts of the GC bank are strapped to ground at st6.

Both flip-flop conductors are controlled directly at a break contact, a1, of impulse relay A, and during the receipt of the tens digit this break contact is alternately switched from one to the other conductor under the control of the Type 44 switch, with the result that conductor R is energized on even impulses, and conductor S on odd impulses, of this digit. This stepping magnet of the Type 44 switch also is controlled at the same contact a1. However, since this switch is stepped only upon release of its magnet, no time delay is introduced on account of the inclusion of the a1 wiper and bank of this switch in the flip-flop circuits; in fact, since the advancement of the Type 45 switch over the above-mentioned intermediate positions takes place independently of the dial pulses, this latter switch is allowed a time interval roughly corresponding to two break periods plus one make period of the dial pulses for skipping any set of five positions. Thus, proper tens positioning of the Type 45 switch is insured even though this switch should lag, due to any accidental cause whatever, behind a given dial pulse. In case the switch is faster than the dial, over-running of this switch is prevented as it was in all the preceding circuits described above.

(3) In the present connector circuit the first group of lines is accommodated at the very beginning of the switch bank; this is made possible by the provision of a "first-pulse-absorbing" relay FA. The arrangement is such that when the connection is abandoned after the dialing of the station digit (which is the first digit dialed into

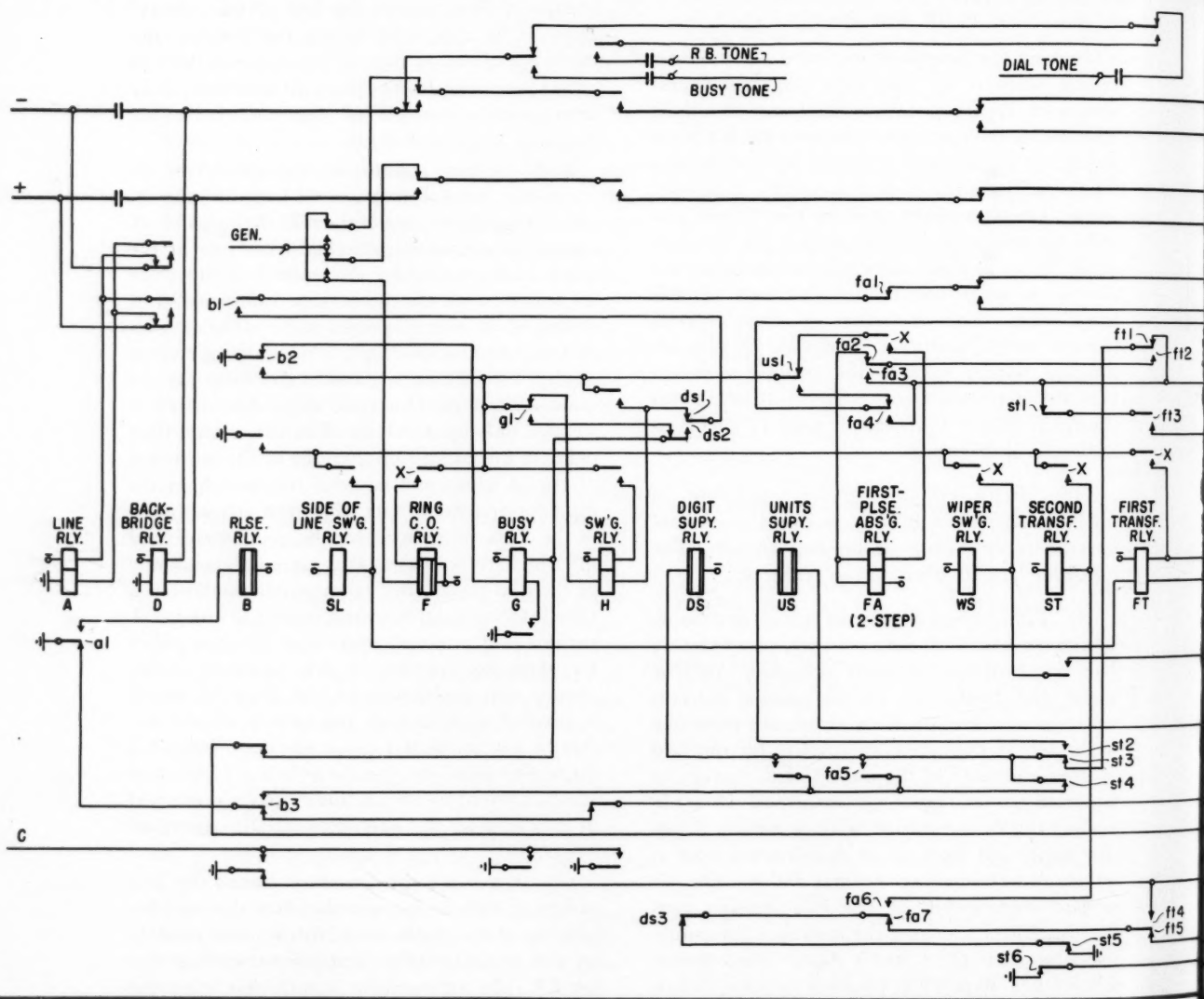
this connector), the circuit is released without either the Type 44 or the Type 45 switch being stepped off normal. Thus, unnecessary homing operations of these switches are avoided.

In the following description of the operation of this connector, those circuits that are believed to be of particular interest will be traced in full:

Relays A and B operate on seizure. Let it be assumed that the call is directed to the subscriber with the directory number 934.

Station digit 9

On each release of A during this digit, motor magnet MM44 of the station-selector switch is energized in multiple with "digit supervisory" relay DS, over the following circuit: ground, a1, b3, st4, st3, ft1, MM44, battery. Upon the release of DS at the end of the digit, "side-of-line switching" relay SL and "first transfer" relay FT operate in series through: ground, st5, ds3, fa7, ft5, wiper A3 in position 9, lower winding of FT, winding of SL, battery. Both these relays lock. SL, by the actuation of its break-make contacts, prepares for transmission of ringing current over the negative side of the called line,



whereby one of the two parties connected to this line is selected in the usual manner. (If the station digit had been 0 instead of 9, relay FT only would have been operated, and due to the non-operation of SL, ringing current would later have been connected to the positive side of the line—i e., the other party would have been selected). Upon the operation of FT the station selector switch is automatically homed by way of ft4, O.N. 44 and int. 44.

Tens digit 3

Upon the first release of A, the first-pulse-absorbing relay FA is operated to its first step, in multiple with DS, through: ground, a1, b3, st4, st3, ft2, fa2, lower winding of FA, battery. When A, reoperating, removes the short-circuit across the upper winding of FA, this relay operates to its second step through: ground, b2, us1, x contact of FA, both windings of FA in series, battery. This prepares the stepping circuit for both switches. Thus, when A releases at the beginning of the second tens pulse, the following self-interrupter circuit is closed for the main switch magnet: ground, a1, b3, fa5 or st4, st3, ft2, fa3, fa4, GC wiper in position 52, int. 45, MM45, battery. Simultaneously, the magnet of the Type 44 switch is energized over another branch of this circuit which

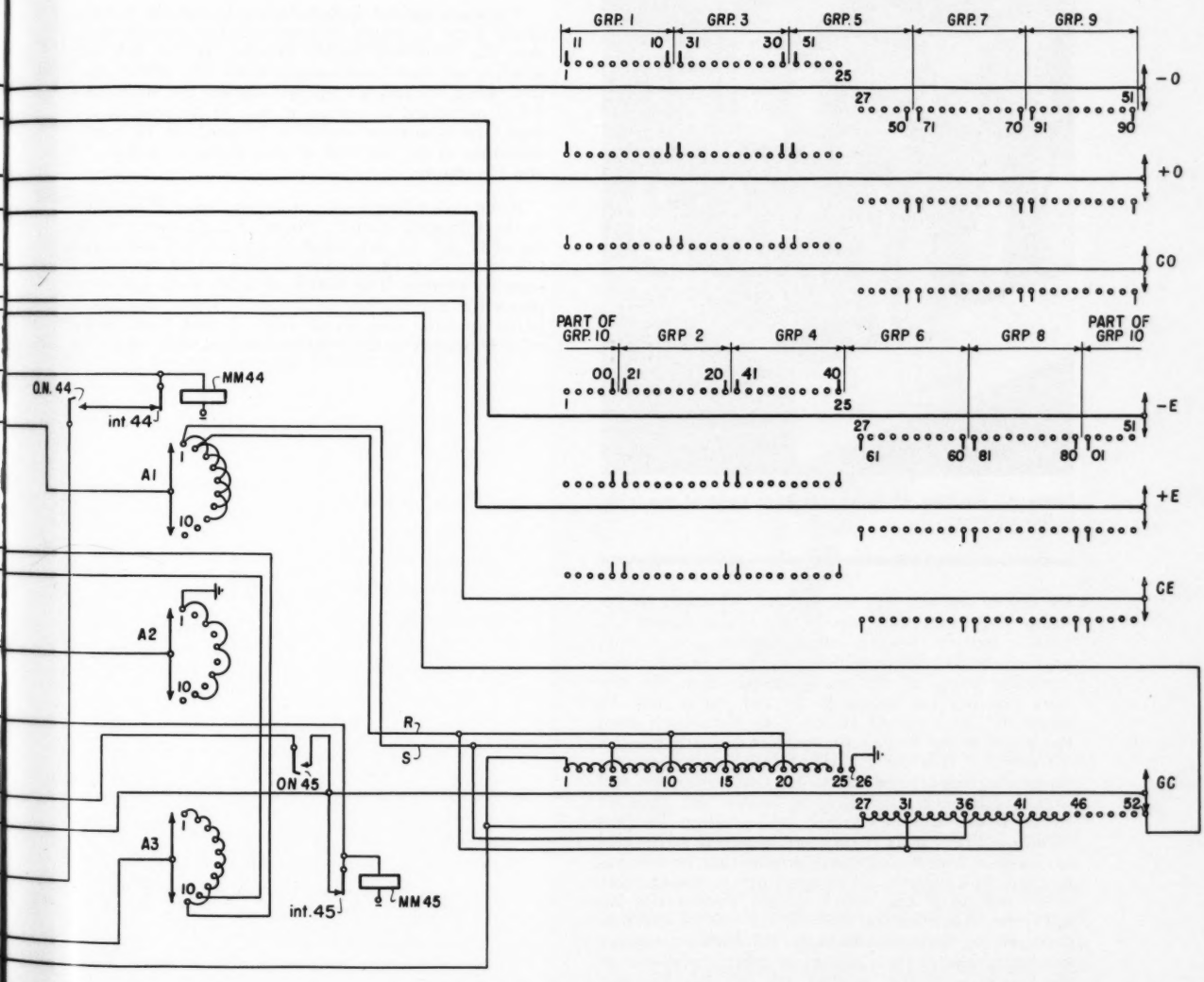


Figure 8. Connector circuit combining group-staggering and impulse-relay control of "flip-flop" circuits.

does not include self-interrupter contact int. 44. Due to GC-bank contacts 1-4 being directly strapped to ground at st6, the main switch moves all the way into position 5, the start position for group 2.

Upon the re-operation of A at the end of the second pulse, MM44 is de-energized and the Type 44 switch moved into position 1, where flip-flop conductor S is connected up over the A1 wiper. Consequently, when A restores at the beginning of the third pulse, another self-interrupter circuit is completed for the magnet of the Type 45 switch through ground, a1, b3, fa5 or st4, st3, ft2, fa3, st1, ft3, A1 wiper in position 1, S lead, GC wiper in position 5, int. 45, MM45, battery. Because of the direct ground connection of GC contacts 6-9, the main switch automatically steps all the way into position 10, the start position for group 3. In any event, the A1 wiper of the Type 44 switch does not switch from the S lead to the R lead, preparatory to further pulses (if any) of this digit, until MM44 is de-energized upon the reoperation of A. It will be appreciated that if a further pulse were to follow, the Type 45 switch would still be "kicked off" position 10, provided only that relay A dies not reoperate at the end of such a fourth impulse, before the switch has reached this position. This provides a considerable safety margin if the switch should temporarily lag appreciably behind the dial. At the end of the tens digit (3, in the case assumed) DS releases, causing the operation of the "second transfer" relay ST in the following circuit: ground, st5, ds3, fa6, ST, battery. ST locks, closes a point in the circuit of wiper-switching relay, WS, and prepares the units stepping circuit for the Type 45 switch.

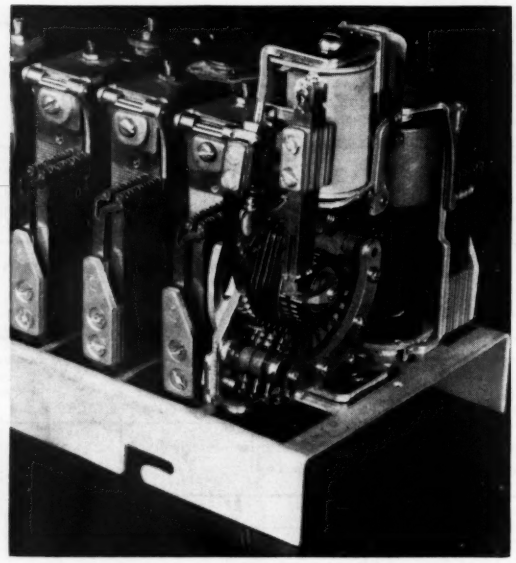


Figure 9. The Type 44 switch mounts in space of one relay, in link equipment.

Since in the case we are describing the tens digit, 3, is an odd digit, wiper-switching relay WS cannot operate, as wiper A2 engages a dead contact, 2, of its bank at the end of the digit. Accordingly the "odd" set of talking and test wipers remains connected up so that the switch is now in condition to be dialed to any of the ten lines of group 3, in response to the receipt of the units digit as described hereafter. Had the tens digit been even (e.g., 2), the A2 wiper would engage a grounded contact, and WS would operate and lock to connect up the "even" set of wipers instead; the Type 45 switch would be in position 5 at the end of the digit and would thus be ready to be positioned on any desired line of group 2 in response to the units digit.

Units digit 4:

The units digit, 4, is dialed directly into the magnet of the Type 45 switch on a one-step-per-impulse basis, over the following circuit: ground, a1, b3, fa5, st2, winding of "units supervisory" relay US, MM45, battery. Both DS and US operate during the digit, and FA is permitted to restore at us1. At the end of the digit, the connector switch is in position 14, corresponding to the 4th line of tens group 3. Relays DS and US restore.

If the called line is idle, switching relay H operates in the following circuit: ground, b2, g1, lower winding of H, ds1, b1, fa1, break contact of WS, test wiper CO in position 14, winding of line-cut-off relay (not shown), battery. The switching relay locks and completes the ringing circuit as usual. When the called party answers, ring-cut-off relay F and back-bridge relay D operate in the conventional manner, and con-

versation between the calling and called parties may begin. On the other hand, if the called line is busy, busy relay G operates over ds2 and its upper winding, locks upon the release of DS and returns busy tone to the calling party.

Should the caller abandon the call after dialing the station digit, the release of A at that time would let FA operate its "X" contact. However, since B subsequently releases also, FA cannot operate to its second step but restores instead. Thus neither of the two switches is moved off its normal position in response to this opening of the calling loop.

Acknowledgements

Credit for the general circuit development work traced herein in outline belongs to the following men: P. Bakker, A. H. Faulkner, C. W. Frank, F. L. Kahn, C. E. Lomax, R. F. Stehlik, and K. F. Steinhauer.

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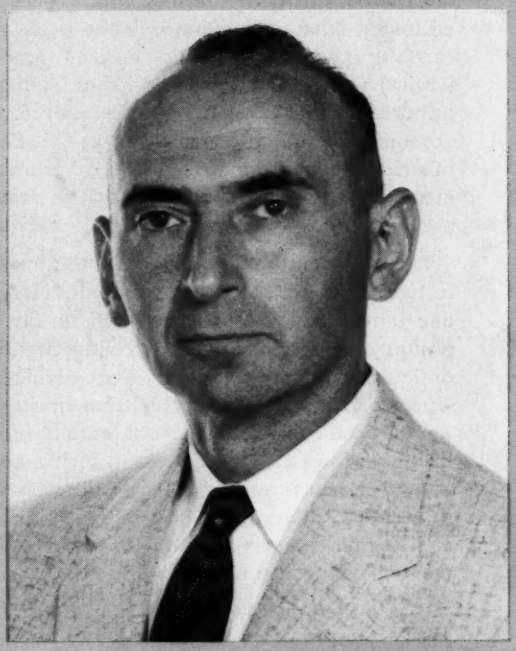

KURT MULLERHEIM began his telephone experience at the installation of London's automatic exchanges in 1929. After receiving his engineering degree (Berlin, 1930) he joined the patent organization of the International Standard Electric Corp. In 1939 he came to the United States to enter the employment of Automatic Electric as a circuit engineer. He later returned to patent practice, and in 1951 re-joined Automatic Electric as a member of its patent department. He is admitted to patent practice before the United States Patent Office and also holds a number of telephone patents himself.

Approximate Computation of the Grade of Service In Primary-Secondary Arrangements

By IMRE MOLNAR
Senior Project Engineer, Automatic Electric Company

Switching channels of maximum efficiency are provided by "full availability" arrangements, whereby every traffic source in a group can reach directly every trunk channel in the group without restriction. For instance, if in a certain situation one hundred trunks are provided, without the possibility of alternate routes, maximum efficiency (that is, maximum amount of traffic-carrying potentiality at a specified grade of service) will be obtained if switches having one hundred trunk outlets are employed. But economic considerations may not permit the use of switches with so many outlets; other arrangements are then sought, to approach as nearly as possible the maximum efficiency.

Primary-secondary trunking is the most effective of these alternative methods. Here our one hundred trunks are connected to, say, four groups of secondary switches having twenty-five outlets each. The traffic sources are divided into separate groups of primary switches having, say, ten outlets each, and the ten outlets of each primary group are subgrouped in such a fashion that, so far as possible, some secondary switches in every secondary group can be reached. There are further refinements of this simple fundamental arrangement.

These methods do not, of course, attain the efficiency of "full availability" arrangements; in considering their use the problem is to determine either the amount by which the traffic-carrying capacity is reduced, or the degree of debasement in the grade of service—or, conversely, the increase in the number of trunks which is needed to carry the same traffic at the same grade of service as with full availability.

Survey of Previous Studies

Several authors have investigated this problem, though the number of published papers is relatively small, considering its practical importance. The amount of observational material is even less; in fact I know of only one set of available data, and that is of rather limited scope and dates back about 35 years.

M. Milon[1] and later C. McHenry[2] published a theory that the probability of congestion in primary-secondary arrangements was derived from the probability for congestion of one, or several, or all secondary groups. This probability was based on the Poisson probability of congestion in a secondary group, and then inserted in the binomial formula. Since the probabilities of congestion in different secondary groups are not independent from each other, application of this theory obviously could not give correct results.

Dumjohn and Martin[3] made a series of measurements with artificial loading in a 2000-line central office having twenty groups of ten-outlet primary switches and ten groups of twenty, ten-outlet secondary switches.

Lubberger in 1924 developed two sets of equations, using a combinatorial approach to determine the secondary group congestion. There was a considerable discrepancy between his results and those derived from the Dumjohn and Martin data.

In a series of articles[4], Jakob Baltzer made an exhaustive study of the mathematics of primary-secondary distribution, and his work is to date the most rigorous approach to the problem. His fundamental approach is similar to Lubberger's; however, starting out with the Poisson probabilities of full occupancy of a secondary group he establishes expressions of the states of occupancy for all combinations of free and occupied secondary groups. From this he calculates, by combinatorial methods, the probabilities of varying numbers of outlets in the different primary groups being unavailable to accept traffic, followed by the probabilities for the state of congestion in a primary group due to certain outlets being unavailable as above and the re-

maining ones occupied by traffic. Finally, the total congestion is obtained by summation over all these states. His approach and formulation appear to be sound, and the numerical evaluations come reasonably close to the Dumjohn and Martin data. An excellent review of Baltzer's theory was prepared by H. T. W. Millar[5].

Max Langer, in various publications, discussed qualitatively several primary-secondary arrangements, but without supporting analytical or statistical data. In contrast to other authors, his conclusions are that primary-secondary arrangements, if they are carefully laid out to distribute traffic evenly among all secondary groups, are practically indistinguishable from full availability and that any debasement in the grade of service is negligible. There are many situations where, no doubt, Langer's conclusions are correct, but there are many others where they are not; and without specifying the degree of tolerance there is no guidance as to what might be considered "negligible".

A further study of the problem was made by C. D. Crommelin[6].

K. Lundkvist used an interesting approach to calculate the congestion in a primary-secondary crossbar arrangement with a single outlet from each secondary switch, to each of a plurality of trunk groups[7]. By assuming random distribution of traffic over free connecting links and certain other independencies, he derives the various states of occupancies and congestions from the number of free and occupied links and trunks on the primary and secondary switches. The transition between the states is governed by the hypothesis of statistical equilibrium, and by the upper limit to the number of simultaneous occupancies. The probability of loss is obtained by summation of the probabilities of congestion during the various states of occupancies. The numerical computation requires the use of graphical methods and a series of successive approximations.

Lundkvist's work is a refinement under specific conditions of an earlier, more general, study by C. Jacobeaus[8] of a variety of congestion problems with primary-secondary crossbar switches.

Jacobeaus subsequently[9] published a very exhaustive mathematical study and experimental analysis of primary-secondary crossbar switching with a large variety of arrangements, in an attempt to arrive at a general theory of primary-secondary trunking. His work includes a study of an arrangement similar to the one treated by Dumjohn and Martin.

Different Approach

It is interesting to observe that, in spite of its inherent soundness, unfortunately no use has been made in over twenty-five years of Baltzer's work as a foundation for engineering tables for primary-secondary distributions, nor, so far as I know, have any attempts been made to verify it experimentally. The reason for this may be found in the extensive computations necessary to its evaluation (although the algebra is straightforward, and there are no other difficulties). The fact that there are several errors in Baltzer's calculations, in spite of the meticulous accuracy of his mathematical derivations, is prima facie evidence of the danger of obtaining incorrect results because of the large amount of computations necessary. Furthermore, the smallest change in the parameters requires an entirely new set of computations, so tabulations would be applicable only to some definite trunking arrangement, which would also make experimental verification more difficult.

It is known that the efficiency of the primary-secondary arrangements which we are considering closely approaches that of "full availability" arrangements; therefore refinements towards greater exactness might seem to have only theoretical interest. The engineering tables now in use are based on very coarse approximations and, as a safety factor, specify 5% more trunks than required with full availability for the same amount of traffic and grade of service, (Example—Table 3 in Automatic Electric Bulletin 485). It is known that this allowance is on the generous side, and assures satisfactory service, so it is understandable that there has been little incentive to explore further refinements. Within recent years, however, primary-secondary arrangements have been increasingly employed in automatic toll switching, where even one or two percent saving in toll circuits is a worthwhile accomplishment, so there now appears to be some justification for re-opening the primary-secondary problem.

A further reason why Baltzer's work has not been followed up may be the manner in which

the actual switching process, and the relative effects of the various physical components on efficiency, were obscured in his equations. In order for a mathematical formula to become popular for engineering applications, its elements should easily be separable, and associable with the physical processes, so that once a set of values has been computed, new sets may be extrapolated for modest variations of the physical arrangement, and the effect of such variations on the accuracy of the new values can be appraised by ordinary engineering judgment.

In the following we shall try a less sophisticated approach than Baltzer's to the primary-secondary distribution problem. Though a fair amount of computation is still required, it is considerably reduced as compared with previous formulas; furthermore, the numerical values are readily available from probability tables. Our result will merely confirm that the efficiency of primary-secondary distributions analyzed in this study closely approaches full availability; that, as a rule, less than 5% allowance in trunk quantities would be sufficient; and that variations in the arrangement (within reasonable limits) have only "second order" effects, so that 5% allowance appears to be safe for almost all applications. Nevertheless, we will have accomplished several worthwhile results: first, we clarify the events which take place in a primary-secondary process; second, we are reassured that our present method of computing is sound and safe; third, we have found that occasionally a primary-secondary distribution can be substituted for full availability, with just a nominal amount of trunk adjustment; fourth, we are enabled to compute fairly easily, and with sufficient accuracy, specific primary-secondary arrangements where engineering judgment does not appear to be adequate; and finally, we can appraise primary-secondary arrangements for which a more refined analysis would not be warranted or cannot be carried out with our present mathematical "warehouse".

Assumptions

In the following discussion we are assuming that the probability of simultaneous occupancies follows Poisson's distributions, with the usual underlying hypotheses of such distributions, viz., statistical equilibrium, random incidence of calls from an unlimited number of sources, and that attempts made during congestion are held with the same holding time as successful calls. (This last hypothesis may appear to need some justification; however, calls which, for instance, find a secondary group congested will be automatically routed through another secondary group, and therefore while the attempted call is lost as far as the first secondary group is concerned, it will not disappear, but in most cases will be completed through another group. Only when there is total congestion and an attempted call cannot be completed could the assumption be questionable; however, the probability of total congestion is small in all cases of practical interest, and then the different distribution formulas give very nearly the same probabilities for such congestions.)

During the main part of our investigation we are further assuming that: (1) the primary switches are divided into separate groups, and each outlet from a primary group is exclusively connected to a secondary switch; (2) the secondary switches are divided into separate groups, and each outlet from a secondary group is exclusively connected to an outgoing trunk; (3) each primary group has the same number of outlets connected to every secondary group, and the incoming traffic is equally divided among the primary groups; (4) that the outgoing traffic from a primary group is equally divided among its sub-groups of outlets connected to the various secondary groups, and therefore, all secondary groups are equally loaded. This means that trunk selection of primary switches takes place at random. Where the mechanics of selection does not permit this, we are assuming that at least the interconnections between primaries and secondaries are arranged in such a manner that equal loading of the secondary groups is assured, and that, as will be derived from our discussion, the probability of congestion of primary groups will be correct in the average over all primary groups. Where the subgroups of primary outlets cannot, because of physical conditions, contain an equal number of outlets, the calculations may be carried out with a fractional number of outlets by interpolation, with the assumption that the result derived by averaging will be maintained over all primary groups.

Preliminary Considerations

In telephone switching problems it is cus-

tomary to consider each switching rank by itself, independently from preceding or succeeding ranks. This approach leads to simple results, because the conditions occurring during congestion are calculable without regard to conditions occurring simultaneously in other ranks. As a rule, the total losses of a system may be obtained by summation of the losses occurring in the various ranks, independently of each other.

The same approach has also customarily been followed in primary-secondary trunking—and in some complex arrangements it is perhaps the only feasible way to obtain practical results. The losses in the primary rank can be computed from the traffic carried by a primary group and the number of its outlets, and similarly for the secondary rank. However, because of the interconnections between the various primary groups and various secondary groups, the congestions in the two ranks are not independent of one another, and two adjustments must be made to the above simple approach:

First, if all outlets of a secondary group are occupied, the secondary switches in that group which are not in use (and therefore the primary outlets connected to such secondary switches) are unavailable; therefore during such periods the availability of primary outlets is reduced, and congestion increased.

Second, when all outlets of a secondary group are occupied, the remaining secondary switches are blocked at the primary outlets, as just explained, and subsequent traffic will be diverted to other secondary groups, as long as such are available. Therefore, considering the secondary rank alone, there is no congestion until all secondary outlets in all secondary groups are occupied. These interdependencies between the two ranks make the determination of congestion quite complicated.

A more realistic view is to consider the whole primary-secondary arrangement as a single rank, with a single state of congestion, occurring at the primary stage. The circuit arrangement is almost always such that when all secondary outlets of a secondary group are occupied the unavailable primary outlets are automatically busied and the incoming traffic will automatically select a secondary group which has available outlets. Therefore, when a primary outlet is found there is also an assurance (barring simultaneous seizures of the same trunk) that the call will be switched to an available secondary trunk.

Congestion in the system can occur only when a primary group has no usable outlets because some are carrying traffic while the remaining ones have no free secondary outlets. This is obvious in systems where the secondary switches are pre-selecting and always stand on an idle secondary trunk (unless all their outlets are busy, in which case all input leads are made busy at the primary bank). In such systems, when a primary outlet is seized the call is immediately extended to the secondary trunk. This is equally true in systems where the secondary switch starts to hunt for an outlet only upon its seizure, if we disregard the possibility that the last free trunk may become occupied from another switch during such hunting.

Computations for a Single Secondary Group

Let us consider a case where the bank of a primary switch has as many outlets as there are trunks available on the secondary bank. In this case we have only one primary group and one secondary group. (There is, of course, no sense in providing secondary switches in such case, since all trunks could be made available from the primary bank outlets directly, but it will serve to illustrate our point.) We now have full availability, and the congestion will be exactly the "full availability" congestion for the total traffic with the number of trunks provided. If we now reduce the number of outlets from the primary bank, and divide the primary switches into several groups according to some formula, but retain the same number of secondary trunks as before, there will be a loss added to the "full availability" loss, whenever all outlets of a primary group are occupied while there are still secondary outlets available. Thus "full availability" efficiency cannot be obtained with primary-secondary trunking, except in the above redundant case.

A single secondary group is often used in toll switching whenever the number of trunks appreciably exceeds the number of outlets from the primary switch and the trunk cost justifies the cost of secondary switching. For instance, if there are ten outlets on a primary switch, and twenty-five outlets on the secondary switches,

we may provide a secondary group whenever the number of trunks is twenty-five or less, but exceeds ten by a number whose value is dependent on the relative costs. In this case, if we designate the "full availability" congestion with x trunks for traffic y as $p(y,x)$, the total loss with 25 trunks will be:

$$p(y,10)+p(Y,25)\ (1-p(y,10))\ ,$$

where Y is the total traffic carried, and y the total traffic divided by the number of primary groups. Usually $p(Y,25)$ is small – perhaps 0.01 or 0.03 – and $p(y,10)$ is still smaller – usually 0.001. Therefore, for all practical purposes, the total loss will be the sum of "full availability" loss and the actual loss of the primary stage – i.e., 0.011 or 0.031. As can be seen, the increase over the "full availability" loss is only nominal; only in exceptional borderline cases could it justify an increase of trunks over the number which would be specified with full availability.

Computations for Several Secondary Groups

The above example represented a very simple case as an introduction to a more general investigation. To make our discussion more tangible, let us assume that we wish to load a group of $N=100$ trunks with $Y=74$ erlangs (TU) of traffic at a grade of service $P=0.010648$. (In this we have already anticipated a 5% trunk adjustment, since with a full availability arrangement only 95 trunks would be required.)

To obtain this efficiency, we are dividing our $N=100$ trunks into $K=4$ groups of 25 each, and connect them to the banks of $K=4$ secondary groups, having 25 outlets each. Our incoming traffic, which is $Y=74$ TU (plus a small amount lost due to congestion, which we disregard in our analysis), is fed through k groups of $n=10$ outlet primary switches. (The number of primary switches is irrelevant to our discussion, but to conform with our fundamental assumptions let us assume that it is a very large – say a thousand or more.) The $n=10$ outlets of each primary group are connected to $n=10$ secondary switches. For the specified grade of service this will not give the most efficient arrangement as far as the number of secondary switches is concerned, but for the present this scheme is the most opportune for our demonstration. The outlets from each primary group are divided into $K=4$ subgroups, two associated with two, and two with three, secondary switches each; for our calculations we assume that each subgroup is associated with $m=2.5$ secondaries.

The number of primary groups can be calculated from the amount of traffic $n=10$ outlets can carry at full availability (disregarding the reverting blocking from occupied secondary groups). The amount of permissible loss in the arrangement may be split up in almost any ration between the loss caused by a limited number of secondary *trunks* and that resulting from a limited number of secondary *switches*. The type of primary-second distribution we are concerned with here is usually justified when the cost of trunks is high compared with the cost of secondary switches, so we should be liberal in the provision of secondary switches and hunband our loss for the provision of trunks. Let us, therefore, allow $p=0.001$ as a grade of service for the number of secondary switches. At this graded service, ten outlets will carry $y=2.95$ TU; so the number of primary groups will be $k=Y/y=74/2.95=25$. The total number of secondaries, though also irrelevant for the probability study, will be $nk=250$.

It may be worth while to pause here for a moment before we proceed further. If our presumptions as to the efficiency of primary-secondary distribution are correct, we need 100 trunks and 250 secondary switches. If we could employ primary switches with 95 outlets, we would need a thousand or more such switches and only 95 trunks – which is, of course, preposterous. Had we connected a trunk directly to a primary outlet without secondaries, we would have needed approximately 178 trunks, or an increase of 78 trunks. If we could have graded the primary outlets, without secondaries, we would have needed 152 trunks, or an increase of 52 trunks. Thus, our primary-secondary scheme is justified when the cost of a trunk is more than about five times the cost of a secondary switch. Actually, as we shall see later, the number of secondaries could be reduced with various artifices to about 120 instead of 250, so the primary-secondary scheme is justified when the cost of a trunk is only 2.3 times the cost of a secondary.

Continuing on our preceding course, congestion in our combined primary-secondary rank can be expressed as the probability of congestion

in any one of the primary groups. This may occur in the following five mutually exclusive events; thus our overall loss will be the sum of these five individual losses:

(a) All Secondary Trunks Busy

Consider first the case in which all trunks from the outlets of all secondary groups are busy unconditionally, regardless of the state of the primary groups. With a "full availability" arrangement and a traffic of Y=74 TU, the probability of N=100 trunks is P'=0.002305; we may consider this value of P' as the probability of the first event, just as we did in our previous case of a single secondary group. In neither case are we theoretically exact, since these values are strictly correct only when the occupancy of trunks takes place at random, and this will happen only as long as the primary groups have available outlets. However, it is safe to assume that when all secondary groups are congested, some primary groups will have no outlets available.

Now, let us take a case where all but one trunk are occupied when one or more primary groups have no available outlets. The last trunk can then be taken only from one of the still open primary groups, and the probability of this is less than at times when all primary groups are in the position to extend calls; therefore the probability of all-trunks-busy is less than with full availability. It is not implied here that the number of lost attempts is reduced; only that, since calls are blocked at the primaries before all the trunks are occupied, the probability of all trunks busy becomes less. Nevertheless, it is felt that the above value of P' is sufficiently close for our use because: first, as we have seen, we have been liberal in the provision of primary outlets, and their probability of congestion is much less than the all-trunks-busy probability; second, as we have seemed to overestimate P', we are on the safe side; and third, for the same reason the other events will tend to compensate for our error.

(b) Primary Group Busy

The second event takes place when all n outlets of a primary group are taken while there are still secondary trunks available. As we have seen, the probability p that n=10 outlets are taken by y=2.95 TU is 0.001; therefore the conditional probability for the second event is $p(1-P')$=0.000998. To the inaccuracy we have already discussed in (a), we have added here a new one, in that the probabilities p and P' are not independent; rather, the probability of total congestion is greater during a period when we know that a primary group is congested than when we know nothing about the state of occupancy. Strictly speaking, therefore, the multiplication law should not be applied. However, under the present circumstances the correlation is small, and for the sake of simplicity the above approach appears to be permissible, particularly since the error is on the safe side.

(c) One Secondary Group Busy

We now consider the event when exactly one secondary group has all its 25 outlets busy, and in the primary group the $(k-1)m$ outlets to the three available secondary groups are occupied, while of the remaining m primary outlets at least one is still idle. As we have said before, in a practical case m will always be an integer, but for our calculation we will take $m=n/k$; in the present case, m=2.5.

If Q is the probability that a secondary group is busy, the probability Q_1 that only one such group out of k groups is busy is:

$$Q_1=(k_1)Q-2(k_2)Q^2+3.(k_3)Q_3-\ldots\pm k(k_k)Qk$$

In our case one group carries Y/k=74/4=18.5 TU with 25 trunks and the probability Q that all 25 trunks are busy is 0.086030. Inserting this value into the equation for Q_1 with k=4 gives 0.262728.

The probability R_1 that $(k-1)$ m=7.5 primary outlets are busy may be computed from an offered traffic of $(k-1)y/k$=2.2125 TU and gives 0.005632.

The probability that at least one of the ten primary outlets is idle is $1-p$=0.999 (or, for practical purposes, 1).

The probability for the event (c) is therefore $Q_1R_1(1-p)$=0.262728 x 0.005632=0.001480. Here again we have disregarded the fact that the above three probabilities are not entirely independent.

If we had considered only the first term in the expression for Q_1, our result would have been 0.001938 instead of 0.001480, which is still sufficiently safe for our purposes.

Likewise, we have calculated the congestion of 0.005632 for 7.5 outlets by the Gregory-Newton interpolation method between the values of the Poisson summation for 7 and 8 trunks. By inspection we would have interpolated about 0.0050 which with the other approximation would have given 0.00172, instead of the correct value of 0.001480.

(d) Two Secondary Groups Busy

The fourth event is that exactly two groups have their 50 outlets busy, and in the primary group the $(k-2)m$ outlets to the available secondary groups are occupied, while of the remaining $(k-2)m$ primary outlets at least one is still idle.

The formula for the probability Q_2 of two secondary groups being busy is the same as the one used under (c) for Q_1, but with only two terms, substituting 2 for k and a new value Q' instead of Q. Q' is the probability of congestion of 50 trunks with $Y/2=37$ TU, and equals 0.023899. Inserting this we obtain $Q_2=0.046656$. Here again, one term giving 0.047798 would have been sufficient.

The probability R_2 that $(k-2)m=5$ primary outlets are busy may be computed from an offered traffic of $(k-2)y/k=1.475$ TU, and equals 0.017422.

The probability that at least one of the ten primary outlets is idle is again practically 1.

The probability for the event (d) is therefore $0.046656 \times 0.017422=0.000813$. The approximation would have given 0.00084.

(e) Three Secondary Groups Busy

The last event is that exactly three groups have their 75 outlets busy, and in the primary group the m outlets to the available secondary group are occupied, while from the remaining $(k-1)m$ primary outlets at least one is still idle.

The probability Q_3 that three secondary groups are occupied is 0.019864; the probability R_3 that 2.5 primary outlets are occupied at 0.7375 TU is 0.111851; thus the probability of event (e) is 0.002222 (approximation would have given 0.00219).

Compound Congestion

The probability of congestion for the complete primary-secondary distribution may be obtained by adding up the probabilities for the five events (a) through (e), assuming that they are mutually exclusive.

(a) 0.002305
(b) 0.000998
(c) 0.001480
(d) 0.000813
(e) 0.002222
$P=0.007818$

Approximations would have given us

(a) 0.00230
(b) 0.00100
(c) 0.00172
(d) 0.00084
(e) 0.00219
$P=0.00805$

– that is, within 3% of the more exact value. The approximate computation can be carried out with the aid of a table of Poisson summations and a desk calculator in about 15 minutes, once the routine is understood.

$P=0.007818$ is somewhat lower than the preliminary objective $P=0.010648$. If our general assumptions as to the completeness, exclusiveness and independence of the events were even nearly correct (and, as we have seen, the errors seemed to be on the safe side), the 5% trunk allowance was generous. In checking the Poisson tables we find that 96 trunks in a full availability arrangement would have given 0.007987 probability for congestion – that is, practically the same as 100 trunks with the primary-secondary distribution. Therefore, a 4% trunk allowance appears to be more appropriate in our example. A recalculation, by the "approximate" method, of the example with 99 outgoing trunks from the secondaries gives $P=0.0097$ as the probability of congestion; this is still somewhat better than our objective.

Nevertheless, for conservative engineering the 5% allowance is to be recommended. When 74 TU traffic is subdivided into 25 primary groups, it cannot be expected that each group will carry exactly 2.95 TU, nor that the busy hour in all groups will exactly coincide. Since the amount of loss with a given number of trunks is not proportional to the traffic, the actual average congestion in the primary stage will be somewhat larger than expected with equal division;

therefore a 5% trunk allowance is a better practical figure.

The question may be asked whether, by a more liberal provision of secondary switches, the number of secondary trunks could not be further reduced. Let us compute the number of primary groups, with the provision that the congestion of the n outlets is only p=0.0001. Ten primary outlets will then carry only 2.2 TU, and $Y/2.2=k=74/2.2=33.64$ primary groups will be needed, with about 336 secondary switches instead of the previous 250. There is no change in event (a). We can practically eliminate event (b). In event (c), nothing has changed in "Q_1", but the probability R_1 that 7.5 primary outlets are occupied has been substantially reduced – nearly to 1/5 of the previous figure. Event (d) is likewise reduced, but to a lesser degree, to about 1/3 of the previous figure. In event (e) the reduction is still less, by about one-half.

All in all, the combined probability of congestion P is now 0.0052 instead of 0.0104. In a full availability arrangement this loss can be obtained with 97.5 trunks instead of the 99 used with primary-secondary distribution; thus, about 1.5% trunk adjustment would suffice. We have now saved 2.5 trunks at a price of 86 secondary switches, and it is a matter of their relative costs as to whether the trade was worthwhile. Theoretically, with p=0.0001, full availability is already very closely approached, but with a heavy outlay of secondary switches. Here again, more than the 1.5% trunk adjustment would be recommended in practice, since the primary group traffic variation with 34 groups would be more pronounced.

As you will recall, with p=0.001 we have traded trunks for secondary switches, at a cost of about five secondaries for a trunk. With p=0.0001 the incremental cost of a trunk is about 40 secondaries. With p=0.001 the objective P=0.0106 cannot be obtained, since the total loss is already consumed by the event (b), with practically nothing left for the other events. If we permit a slightly higher value for P, we may save trunks at a cost of four secondaries per trunk over a graded multiple arrangement without secondaries (instead of five secondaries per trunk with p=0.001). The incremental cost per trunk with p=0.001 over p=0.01 would be about ten secondaries per trunk – of course always assuming approximately 74 TU traffic, 25-outlet secondaries, and 10 secondaries per primary group.

Had we used 50-outlet secondaries instead of 25, the number of trunks could have been reduced from 99 to 96, which is only one more than the number needed with full availability. The number of secondaries at p=0.001 remains unchanged – 250. The congestion consists now only of events (a), (b) and (c), with probabilities 0.007987, 0.001000, and 0.001547, respectively – a total of 0.010534. Each trunk was saved, over our first example, at the incremental cost of eighty-three 50-point secondaries instead of 25-point secondaries. This last conclusion demonstrates that the 4% trunk adjustment is valid only for the example studied, and the need for adjustment is reduced with a diminishing number of secondary groups.

0.00230
.00100
.00172
.00084
.00021
0.008

Experimental Results

We may now check our approach against the Dumjohn-Martin data obtained by artificial traffic tests. The Dumjohn-Martin experiment was undertaken for 100 trunks from secondaries with a traffic of 75 TU. Primary and secondary switches had ten outlets each. There were twenty primary groups, and a total of 200 secondary switches divided into ten secondary groups. The following table shows the probabilities that the number of secondary groups listed in the first column would be simultaneously occupied. The second column gives the data obtained by Dumjohn and Martin, and the third column was calculated according to Baltzer's equations, while the fourth column was directly read out from Poisson tables as the probability of loss with 10x trunks at 7.5x TU.

0.046656
0.017422
93312
93312
186624
326592
46656
0.000812820

Sec. Groups	Dumjohn-Martin	Baltzer	Based on Poisson
0	0.4287	0.441	0.4544
1	0.2554	0.262	0.2236
2	0.1460	0.149	0.1248
3	0.0827	0.076	0.0747
4	0.0445	0.022	0.0463
5	0.0201	0.011	0.0292
6	0.0135	0.0061	0.0187
7	0.0049	0.0051	0.0120
8	0.0019	0.0022	0.0078
9	0.0012	0.0013	0.0051
10	0.0002	0.0009	0.0034

The agreement of Dumjohn-Martin with both of the formulas does not seem bad, considering the discrepancies generally found in telephone traffic problems. The last four values obtained by us appear to be excessively high, but this is usually the case whenever the Poisson summation is used towards the "tail end" of the distribution, with many still-significant terms added together, as compared with a combinatorial or binomial distribution. However, as we have seen, these end values have a diminishing significance on the overall congestion, so we may trade some slight accuracy for a saving in labor.

Actually, a statistical analysis reveals that the agreement of either of these two sets of values with the experimental set is not too good, but other formulas which were calculated gave far worse and completely useless results. And a chi-square test reveals that the Poisson values give a better fit to the experimental set than Baltzer's formula. Our method did not require any calculation other than a total of four interpolations, while the other requires a very lengthy computation.

The expected average number of primary outlets to be blocked by fully occupied secondary groups can be estimated by the product of (10 x first column x fourth column), which gives 13.7 outlets. Baltzer's method gives 10.4, while the experimental expectation is 12.2. Here again, our method appears to give conservative results.

Baltzer estimates the loss for this arrangement to be 0.016. We may calculate the loss by an approximate method, where the probabilities of the events (a) and (b) have the same meaning as in our previous example. There are nine more events where the probabilities $Q_1 \ldots\ldots Q_9$ may be taken as approximately the values in the fourth column of the preceding table. These Q_i values are multiplied by the probability R_1 that in a primary group $10-i$ outlets are occupied by a traffic of $3.75(10-i)/10$. For the compound congestion we obtain 0.021 instead of Baltzer's 0.016. In a full availability arrangement for 75 TU at a grade of service of 0.016, a little less than 95 trunks are needed: Baltzer estimates 100, while we would estimate 102. Baltzer's result gives a little over 5% trunk allowance, our trunk allowance is about 7%. However, it is well known that whenever traffic engineering is based on a Poisson distribution we end up with more trunks than with other types of distributions. As the 95-trunk estimate for full availability was also based on a Poisson distribution, Baltzer's allowance is actually higher than 5%, compared with the type of distribution he is using.

Graded Outlets

Returning to our previous example of 74 TU traffic and 99 or 100 trunks, we have seen that this availability was achieved at the price of using 250 secondary switches. We have also seen that such an arrangement could not be justified unless the cost of a trunk exceeds the cost of five secondary switches. Actually, we can do considerably better.

We have divided the source of traffic into twenty-five groups of primary switches, and assigned a secondary switch to every one of the ten outlets of each primary group. If a primary group carries 2.95 TU, the average load per outlet is 0.295 TU. We know that when switch outlets of availability of the order of 10 are arranged into a larger group of graded outlets, a much higher efficiency per outlet can be obtained: for instance, the efficiency of a graded group of 40 outlets at $p=0.001$ is at least $v=0.37$ TU per outlet, or an increase of 25%. We could, for instance, divide our primaries into $k=5$ graded groups, each group carrying $y=Y/k=74/5=14.8$ TU. Each primary group would then have $n=40$ outlets at an efficiency of 0.37 TU per trunk, which provides almost exactly p=0.001 for the primary stage. The number of secondary switches is now $5 \times 40=200$—a reduction of 20%, of course. The cost of a trunk need now be only four times the cost of a secondary switch, to prove-in the arrangement. But let us first see whether we have changed our several events.

The development of a probability theory for graded multiples has intrigued almost all mathematicians who have pursued telephone traffic problems, but in spite of a variety of very ingenious approaches and the seeming simplicity of the problem it remains as puzzling today as ever. A number of formulas have been developed (some having no similarity to one another), but most of them are very complex and difficult to calculate, all of them are restricted to specialized arrangements, and, unfortunately, none of them gives results which come even close to the "facts of life". [Since I wrote this, Roger I. Wilkinson has published a paper on "Theories

for Toll Traffic Engineering in the U.S.A." (Bell System Technical Journal, March, 1956) which includes a new, practical approach to traffic-grading problems.] For engineering purposes, several telephone organizations have developed trunk-capacity tables by mixing approximate probability theory, artificial traffic experiments, actual traffic observations, empirical interpolation formulas, common sense and expediency. These tables serve the purpose very well, even though they may give somewhat different answers to the same question under apparently identical conditions.

Since the "probability theory" approach is unsurpassable, for the time being, for ordinary graded multiples, it would be useless to attempt to improve upon it when we have the added complexity of primary-secondary distribution. Instead, we will refer to the graded-multiple tables which are in use in the United States, accept the data given by these tables as facts, and try to apply them, as well as we can, to our problems.

For computations on primary-secondary arrangements with graded multiples, we consider then the same five mutually exclusive events as before. In event (a) — All secondary trunks busy – there is no change, since the full availability congestion P' is independent of the manner in which the primary outlets are arranged. Also in event (b) — Primary group busy — there is no change, since we now compute our graded primary groups to provide a grade of service p= 0.001, as before.

In events (c), (d), and (e) —One, two and three secondary groups busy — the first factor, Qi (the probability of i secondary groups having all their outlets simultaneously occupied) as well as the third factor (which we consider as 1), remain unchanged. But the second factor, Ri— namely, the probability that the primary outlets to unblocked secondaries are occupied — is more difficult to estimate when the outlets are graded. First, the assumption which we have previously made, that all primary outlets carry equal traffic (or if not, the traffic will average out over a large number of primary groups) is no longer valid because it is inherently impossible to completely equalize traffic with conventional grading methods, and furthermore the number of primary groups has been reduced to five, which may not be sufficient to insure equalization. Second, as we have already pointed out, there is no satisfactory analytical method of estimating the amount of traffic carried by each outlet, or even for any group of outlets in a grading plan. Third, since the principle of grading requires that certain outlets are to be reserved for the peak periods in traffic, the correlation between the states of occupancy of secondary groups and the occupancy of certain primary outlets must be greater than in the example without grading.

Fortunately, there is this compensating factor: in laying out a grading plan an effort is automatically made to equalize the traffic over the various outlets as well as one can; in fact, only by this means can the efficiency of graded outlets be achieved. So, lacking a better hypothesis, we have no choice but to work with the average load per outlet — over the whole grading and all groups. This occupancy will be, of course, y/n=14.8/40=0.37 TU.

It now remains to calculate the probability Ri — for instance in the event (c), that three-fourths of the primary outlets accessible to any one primary switch are occupied. This condition may be considered equivalent to the state when a certain group of 30 outlets out of 40 in a primary group are occupied when a traffic of 30 x 0.37=11.1 TU is carried by these outlets. Here is our next stumbling block, since we have no exact way to calculate this probability in a graded multiple. So we have to take recourse to an artifice for which the only excuse is that there is no alternative!

Examination of the Poisson table reveals that if we pick two pairs of traffic loads and corresponding numbers of trunks for the same grade of service — say 4 TU with 8 trunks and 15 TU with 22 trunks — then 8 TU with 16 trunks will give about the same grade of service as 30 TU with 44 trunks, or 16 TU with 32 trunks about the same as 60 TU with 88 trunks. Of course this is all approximate, but it is close enough to encourage us to try our proposed procedure.

Accordingly, we now make the assumption that the probability of occupancy of r trunks with a traffic of t in a graded arrangement is the same as the probability of occupancy of r trunks with a traffic of u in a full availability arrangement, if the number of trunks R was originally established to give the same grade of service with traffic U in full availability as with traffic T in a graded arrangement. For in-

stance, we computed $R=40$ outlets for $T=14.8$ TU at $p=0.001$. In a full availability group, $U=23.25$ TU will give the same grade of service with $R=40$ outlets. The probability that $r=30$ outlets are occupied with $u=17.44$ TU is 0.004148 in a full availability group, and so by our reasoning, 30 outlets in a graded group should be occupied by $t=11.1$ TU with the same probability, $R_1=0.004148$.

From the above, the probability of event (c) will be $Q_1R_1=0.326910 \times 0.004148=0.001356$, as compared with the previous value of 0.001841.

Through similar reasoning, the probability of event (d) is $0.046656 \times 0.015967=0.000745$, and of event (e) $0.019867 \times 0.070844=0.00141$ (the probabilities of corresponding events in the full availability case were 0.000813 and 0.002222, respectively).

The compound congestion for the distribution is:

(a) 0.002305
(b) 0.000998
(c) 0.001356
(d) 0.000745
(e) 0.001410

$P=0.006814$

In the full availability case, $P=0.008179$, so there appears to be an improvement caused by grading. But (just so we do not derive an exaggerated satisfaction from this conclusion), we must remember the unsupported hypothesis and crudeness of the method by which we have arrived at it! Furthermore, the above demonstration was carried out in only one example, and I have not produced an analytical expression that would permit generalization. I do believe that we are on a reasonably safe ground, but the most that we can say is that there is no reason to suspect that the grading arrangement gives efficiency inferior to that of full availability.

Encouraged by our grading method, the question may also be asked whether further economies could be obtained by grading the secondary outlets – for instance, by combining the four secondary groups into one large graded group. The answer is a definite "No". As we have seen, we already have virtually full availability, with about 4% trunk adjustment. This adjustment was required not because of the limited access of the secondaries, but because of the blocking of some primary outlets.

It was our contention all along that congestion actually occurs always at the primary outlets. Now, such an outlet is blocked whenever a secondary switch has all its 25 outlets occupied, and this is true whether those outlets are graded or in a straight multiple, as long as the average traffic per outlet is the same. As this is Y/N, and within 4% of the full availability loading, further improvement does not seem to be feasible.

Partial Secondary Distribution

Following up our last thought, while a saving of secondaries by grading of secondary outlets does not seem to be practical, a further economy in secondary switches is possible by one form of grading – which, however, is not immediately apparent as being such.

We have estimated that in the grading arrangement in our example the average loading of a secondary switch is $v=0.37$ TU. To make the example more definite, we shall assume that each of the five primary groups is divided into $S=8$ subgroups, with the first three outlets of each subgroup brought out individually and the remaining seven outlets commoned between the various subgroups of a group in some manner to provide leads to sixteen secondaries. The first three outlets take care of twenty-four leads (all together, forty outlets) as prescribed by the grading.

Now, an analysis of the grading will reveal that when approximately $y/s=g=14.8/8=1.85$ TU is offered to each subgroup, the first of the three individual outlets will carry 0.64 TU, the second 0.53 TU, and the third 0.36 TU; the rest is of no interest for our purpose. Obviously, the first two outlets are already loaded higher than the average of the group by virtue of being the first choices for the traffic, so it would serve no purpose to connect a secondary to them. But, as we can see, the same conclusion would not apply to the third outlet. Therefore, we may just as well connect the first two outlets of each of the eight subgroups of each of the five groups to an outgoing trunk directly without the intermediary of a secondary – sixteen outlets in each group, eighty trunks altogether. Each of the remaining $Sm=5 \times 24=120$ outlets are then

connected to a secondary – altogether, 120 secondaries.

We have now reduced the number of secondaries from 200 to 120 as promised earlier, and the primary-secondary distribution is justified whenever the cost of a trunk exceeds 2.3 times the cost of a secondary.

As the average load of the first two (direct) outlets is $(0.64+0.53)/2=0.585$ TU$=h$, while the average load of an outgoing trunk (assuming a total of 100 trunks are provided) is $Y/N=0.74$ *TU*, there is left in each of the $2ks=80$ direct trunks some excess capacity which we have to use up, or our presumed economy will backfire! Therefore, each of these 80 direct trunks is also connected to the outlets of the various secondary groups exactly as in the preceding examples.

It remains now to find out what these various changes have done to the congestion. As it was pointed out before that even ordinary grading arrangements cannot yet be satisfactorily analyzed mathematically, and the addition of a secondary distribution has already forced us into a speculative approach, the present added complication must take us onto still more shaky ground!

There are now 80 trunks which appear as both direct trunks and secondary outlets, while 20 trunks receive traffic only through the secondaries. Obviously we cannot divide equally among the 100 trunks the total amount of traffic passing through the secondaries, and add to each of the 80 direct trunks also the traffic they receive directly. Neither can we assume that the direct trunks will receive the full amount of traffic $h=0.585$ TU from the primaries, as they would had they not also received traffic from secondaries.

As we cannot estimate the exact traffic distribution, we are forced to make some assumptions, and our conclusions will be no more plausible than the premises on which they are based. Here again, there is no excuse for these assumptions except that there are no others known to me which could be better justified, and as long as there is some purpose in appraising the state of congestion of this primary-secondary arrangement (and until better premises are found) such speculation must be guided by the most reasonable premises available to us:

First, that the number of trunks remains unchanged, or (which means the same) that the average load per trunk remains unchanged: $Y/N=0.74$ *TU*. Of course, we do not know this, because it is the very thing we wish to find out. But if we proceed from this assumption and can then confirm the grade of service at the end (without just operating in a vicious circle with an identity!) we will at least have proved the assumption not invalid.

Second, that the traffic between the various trunks is in a way equalized. As in the preceding case, we do not imply by this that all outlets will carry the same load (in fact, our next assumption is that the outlets are not equally loaded). However, we do assume that the arrangement of outlets from the different primary groups and secondary switches, as well as the assignment of direct and indirect outlets to the secondary banks, is such that it is permissible to work with the average load of the direct, and the average load of the indirect, outlets and trunks, and also with the average load carried over the first- and second-choice primary outlets. This assumption seems to me quite legitimate.

Third, that the direct trunks will obviously carry a higher load than the twenty indirect trunks, and the fraction of the traffic received by the direct trunks from the secondaries will be less than the load carried by the indirect trunks. This assumption is unquestionably true.

Fourth, that the traffic received by the direct trunks from the first two primary outlets will be less than it would be if these trunks would not appear also on the secondary banks. This corresponds to the second statement of the third assumption (above) and is equally true.

Fifth, that it is permissible to evaluate the third and fourth assumptions in the following manner. We designate the average traffic received by a direct trunk from the first- and second-choice primary outlets as A, the traffic received by the same trunk from a secondary outlet as B, the traffic received by an indirect trunk from a secondary outlet as D. Consider the traffic $g=y/s$ offered to a primary subgroup. Then $A=ip(0)f(g)$, where i is the proportion of time when the trunk is available to receive traffic from the primary outlet and is $1-B$, $p(0)$ is the probability that no traffic is received from the primary switch, and $f(g)$ is a traffic distribution function such that, for instance, $p(0)f(1.85)=h=0.585$, in our example. Likewise, $B=(1-A)D$. If A and B and D were independent and

random quantities, the above relations would be reasonable, but B and D are definitely not random, and there is a correlation between A and B, and also between A and D. There are means of making approximate corrections for non-randomness, but it would be too complex in this case, nor would it be practical to compute the correlation. Neither of these omissions do I consider serious enough to prevent us from drawing conclusions for the present purposes.

Sixth, that in the present case B=0.4, approximately. This value was obtained by successive approximations, and will satisfy the following computations.

The average traffic received by each of the first two primary outlets will be: $A=(1-B)p(0)f$ (1.85) =0.6x0.585=0.35. Eighty direct outlets will carry 28 TU. The amount to be carried over to the secondaries is 74-28=46 TU. The average traffic carried by each of the 20 indirect trunks can be calculated from the relation based on the fifth assumption: $80(1-A)D + 20D=46$; so D=0.64 TU. The average traffic received by each direct trunk from secondaries is $(1-A)D$=0.415, which is near enough to the value of B=0.4 suggested in the preceding paragraph. The total average load of a direct trunk will be 0.35 + 0.415=0.765 TU. The total traffic carried by the 100 trunks will be: 0.765 x 80 + 0.64 x 20=74 TU (but we should not attach any significance to this return to our starting point, since in the above calculation we have proceeded in a circle, on the basis of the first assumption; thus any *other* result would indeed have been surprising!) This, however, is not the case in the next consideration.

The total load carried by the secondaries is 46 TU. The average load carried by a secondary is w=46/120=0.383 TU, which is only slightly larger than the v=0.37 TU obtained in the preceding example with 200 secondaries.

The probability of compound congestion is again the sum of several events. The probability for event (a) remains unchanged. Event (b) will be considered later. The other events take place when one or more of the secondary groups are occupied and the pertinent primary outlets to the unoccupied secondary groups as well as the pertinent direct outlets are busy. The probability Qi that one or more secondary groups will have all their outlets simultaneously occupied is likewise the same as in the preceding examples, since these probabilities depend only on the total load carried by the trunks in an arrangement which is virtually full availability, and not on the manner these trunks are connected, so long as we can assume that the loads on the groups of 25 trunks are equalized between the four secondary groups.

The occupancy of the primary outlets, however, seems to be unmanageable. It may be appraised by the following reasoning: A congestion will occur only under the conditional probability *Prob (r,z)* that certain direct outlets z are busy, and that at the same time certain combinations r of outlets to secondaries are busy.

A second unconditional probability, $q(r)$, refers to the event that certain r secondaries are busy. In the preceding example of graded multiple outlets without direct trunks, we have concluded that the probability of congestion for r trunks may be considered the same as for r trunks in an equivalent "full availability" group, which was established for the same number of total outlets, and the same grade of service. The persent situation is similar: we have established the grading with the same 40 outlets at the same grade of service, and the average traffic carried by the 24 outlets to the secondaries is approximately the same as in the previous case.

There are, however, two important changes. First, as we now consider only the outlets beyond the second choice, the traffic over these 24 outlets will be less random than the average over the 40 outlets in the previous case; this should increase the probability of congestion. Second, the probability of congestion of r (say, 18 outlets out of a total of 24) is greater than $40r/24$ (say, 30 outlets out of a total of 40) if the average traffic carried is the same in both cases. An analysis of the grading indicates that an average traffic of 0.383 for each of the 24 indirect outlets is equivalent to 19.8 TU carried by 40 graded outlets, which is equivalent to 25.8 TU carried by 40 outlets in a full availability group.

Based on this fact, and assuming that the probability of 6 out of 8 indirect outlets in a primary subgroup being occupied is the same as that of 18 of the 24 outlets in the primary group, we obtain approximately $q(r)=q(18)=$ 0.014.

To obtain the probability R_1, we must multiply $q(r)$ by $q'(z)$, which is the conditional probability that z direct primary outlets are occupied when it is known that certain r of the indirect outlets in the same primary groups are also occupied. The unconditional probability that z primary outlets are occupied is, of course, $0.765z$, which is 0.585 if we consider two specific direct outlets. However, this probability must change when it is known that at least r=18 of the indirect outlets are occupied at the same time, since obviously in a grading later choice trunks would not be occupied unless the early choice outlets were unavailable (disregarding, of course, the period when an early choice outlet might have become free before a new call arrived which could have occupied it). Actually, we did not specify that exactly r indirect outlets are occupied, but that certain r indirect outlets are occupied, while some of the remaining indirect outlets of the same primary group must be unoccupied though blocked. On the assumption that at least r outlets are occupied, the expectation of the occupied outlets can be computed; in the example, r=18 is now 19.3 outlets, or 80.3% of the 24 indirect outlets. We might now be tempted to assume that 80.3% or 12.85 of the 16 direct outlets are also occupied – that is, a probability of 0.803 for the occupancy of a direct outlet, and for $q'(2)=0.803^2=0.645$. However, from what has been said it is apparent that when 80% of the later-choice outlets are busy, almost all direct outlets must be unavailable. Suppose that during this period there is a probability of 0.95 that a direct trunk is occupied, $q'(2)=0.95^2=0.9$. Then $R_1=q(r)q'(z)=0.014 \times 0.9=0.0126$ and the probability of event (c) will be:
$Q_1 R_1=0.327 \times 0.0126=0.00412$.

Event (d) assumes that a certain 12 of the indirect outlets are occupied, and $q(r)=0.040$. In this case we are not justified in supposing that nearly all direct outlets are taken, although the fact that two secondary groups are completely busy indicates that the traffic is heavy. So instead of the average direct load, 0.765 TU, we may work with the previous increased occupancy per direct trunk – say 0.95 TU; thus $q'(z)=0.95^2=0.9$. Then $R_2=0.040 \times 0.9=0.036$, and the probability of event (d) will be:
$R_2Q_2=0.036 \times 0.046656=0.00168$.

Event (e) assumes that a certain 6 of the indirect outlets are occupied, and $q(r)=0.118$. In this case we have even less reason to suspect that nearly all direct outlets are taken, except that we know that when three secondary groups are completely busy the traffic must be very heavy. We may use again $q'(z)=0.9$; then $R_3=0.118 \times 0.9=0.106$, and the probability of event (e) will be $Q_3R_3=0.019867 \times 0.106=0.00211$.

It still remains to compute the probability for event (b) when all primary outlets in a subgroup are occupied. Now we might be tempted to assume that this probability is p=0.001, the probability of congestion of 40 outlets in a graded group with Y=14.8 TU. This would be correct, had we removed an average of $h=p(0)f(1.85)=0.585$ TU by each of the first two outlets in each subgroup. Actually only A=0.35 TU was removed and passed on to the third outlet $g-2A=1.85-0.70=1.15$ TU, assuming that each subgroup carried the same g=1.85 TU load (which is the most favorable case). An analysis of the grading shows that now the probability of all ten outlets of a primary subgroup being occupied is approximately p=0.0075, and the probability of event (b) is thus approximately $p(1-P')=0.0075$–a very considerable increase over 0.001.

The compound congestion will then be:

(a) 0.0023
(b) 0.0075
(c) 0.0041
(d) 0.0017
(e) 0.0021
P=0.0177

which is now appreciably higher that the previous objective P=0.010. In a full availability group this grade of service is obtainable with slightly over 93 trunks at 74 TU, and two trunks would have to be added to obtain the objective, 0.010. With the present partial secondary arrangement, the number of trunks would accordingly have to be increased to 102, instead of the 100 trunks planned, or the 99 trunks with full primary-secondary distribution. (It should also be remembered that the analysis of the graded full primary-secondary example indicated that even 98 trunks might suffice.)

In conclusion it may be stated that, provided the limitations of the above analysis are acceptable, the efficiency of the primary-secondary arrangement is appreciably reduced by connecting

first-choice outlets directly to outgoing trunks and eliminating the corresponding secondary switches. In the example treated here the loss of efficiency, relative to full availability, is almost double that of a full primary-secondary distribution. It requires about 7% trunk adjustment instead of 4%, and this would have to be increased if an added margin of safety were required. The incremental value of a trunk in the partial-secondary graded case versus the full-secondary graded case is in this specific example about 20 secondaries; this suggests that partial-secondary distribution should not be employed when the cost of trunks is high and their number is large.

As the above tabulation shows, the main cause of the loss of efficiency in primary-secondary arrangements is the large amount of congestion of event (b), which is due to the fact that the direct trunks receive traffic also from the secondaries, and thereby the indirect outlets are loaded higher than might be assumed from the theoretical grading with full secondary distribution. While many phases of the foregoing analysis are debatable, in general we were conservative; ultimate judgment on this analysis must be deferred for practical verification.

List of Symbols

(a) Event that all trunks are occupied.

(b) Event that all outlets of a primary group are occupied.

(c) Event that the outlets of one secondary group are occupied, and primary group is congested.

(d) Event that the outlets of two secondary groups are occupied, and primary group is congested.

(e) Event that the outlets of three secondary groups are occupied, and primary group is congested.

g Traffic carried by a subgroup in a graded primary group.

h Average traffic of each of the first two choices in a graded group.

k Number of primary groups.

m Number of outlets from a primary subgroup.

n Number of outlets from a primary group.

p Probability that all outlets of a primary group are occupied.

$q(r)$ Probability that r indirect outlets in a primary group are occupied.

$q'(z)$ Probability that z direct outlets in a primary group are occupied.

s Number of primary subgroups.

v Average traffic of a graded primary outlet.

w Average traffic of a secondary switch.

y Average traffic of a primary group

A Average traffic received by a direct trunk from a direct primary outlet.

B Average traffic received by a direct trunk from a secondary outlet.

D Average traffic received by an indirect trunk from a secondary outlet.

K Number of secondary groups.

N Number of trunks

P Total probability of congestion of N trunks.

P' Probability of congestion of N trunks in a full availability group.

Q_1 Probability that i secondary groups are occupied.

R_I Probability that all unblocked primary outlets are occupied when i secondary groups are occupied.

Y Total traffic.

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IMRE MOLNAR began his telephone work in Europe on major installation projects in 1921. After graduating in Communication Engineering (Berlin, '30), he worked for the Automatic Electric group abroad in installing, circuit design, and transmission. In 1937, Automatic Electric assigned him to circuit design, and in 1943, he beame Project Engineer. He received a Ph.D. in Electrical Engineering from Northwestern University in 1950. Dr. Molnar is a member of the American Institute of Electrical Engineers and a senior member of the Institute of Radio Engineers.

Errata

On page 38—right-hand column, line 11 and following, should read:

"ratio between the loss caused by a limited number of secondary *trunks* and that resulting from a limited number of secondary *switches*. The type of primary-secondary distribution we are concerned with here is usually justified when the cost of trunks is high compared with the cost of secondary switches, so we should be liberal in the provision of secondary switches and husband our loss for the provision of trunks."

On page 39—formula "$Q_1 = \ldots$" should read:

$$Q_1 = \binom{k}{1}Q - 2\binom{k}{2}Q^2 + 3\binom{k}{3}Q^3 - \ldots \pm k\binom{k}{k}Q^k$$

On page 41—third paragraph, line 5:
"p=0.001" should be "p=0.01"

On page 43—Qi should be Q_i
Ri should be R_i

On page 44—fifth paragraph, line 1:
"P=0.008179" should be "P=0.007818"

In last line on page:
"Sm=5 x 24=120 outlets" should read
"Sm=5 x 24=120 outlets"

On page 45—right-hand column, line 7:
". . . we will at least have proved the assumption not invalid" should read: ". . . at least we have not proved the assumption to be invalid".

On page 46:
"Qi" *should be* "Q_i"

In right-hand column, line 16:
"A second unconditional probability . . ." should read "The second unconditional probability . . ."

On page 48:
"Q_1" should be "Q_i"
"R_1" should be "R_i"

"(3) Post Office Electrical Engineers Journal, July" should be ". . . July, 1922"

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